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Full Name of Author — Nom complet de l'auteur

IAN HUMPHREYS

Date of Birth — Date de naissance

14th JUNE 1956

Country of Birth — Lieu de naissance

ENGLAND.

Permanent Address — Résidence fixe

c/o GRANVILLE
THE GABLES
TOUCHSTONE CLOSE
CHARD, SOMERSET, ENGLAND.

Title of Thesis — Titre de la thèse

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Name of Supervisor — Nom du directeur de thèse

DR. R.B. WILBERG.

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Single Aiming and Reciprocal Tapping: A Comparison

by

Ian Humphreys

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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PERMANENT ADDRESS: 449L Michener Pk.
Edmonton,
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Canada.

DATED June 9th 1982

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled

Single Aiming and Reciprocal Tasks:

A Comparison

submitted by Ian Humphreys

in partial fulfilment of the requirements for the degree of

Master of Science

R. B. Welford
.....
Supervisor

Rex Ackerman
.....

Jay Bishop
.....

Date June 9th 1982

ABSTRACT

Two experiments were conducted in order to compare characteristics of single aiming and reciprocal rapid aiming tasks. It was hypothesized that the two movement classes, reciprocal and single aiming, differed in the demands they placed on attentional processes. The result of this proposed difference in attentional demand was thought to account for the observation that the performance of reciprocal tapping tasks was predicted by Fitts (1954) Law, while the performance of single rapid aiming movements was not. Conversely, performance of single aiming tasks was predicted by the Schmidt et al (1978, 1979) formulation which could not accomodate reciprocal tasks. Experiment One provided some evidence to support the theory that when subjects operated below the capacity of the motor processing system the performance characteristics of the aiming movements whether single or reciprocal may be predicted by the Schmidt et al formulation. When subjects operated beyond the capacity of the motor system then characteristics of the aiming response may be predicted by Fitts' Law. Experiment Two was an attempt to manipulate the demands placed on a subjects attention when performing a reciprocal movement aiming task. The object of the experiment was to demonstrate a move from situations predicted by the Schmidt formulations to situations predicted by Fitts Law as demands on attention in the reciprocal movement task increased. Due to methodological problems this experiment failed to provide useful data.

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The earliest mathematical relationship between the speed and accuracy of movement was provided by Fitts (1954). Fitts demonstrated experimentally that movement time (MT) was a linear function of the index of difficulty (ID) which was defined in information terms as:

$$\log_2 2A/W$$

where A was the amplitude of movement and W the width of the aimed for target. This relationship, celebrated as Fitts' Law, accomodated data from numerous experimental sources (Knight & Dagnall, 1967; Fitts & Peterson, 1964; Fitts & Radford, 1966). Although attempts were made to improve upon Fitts' equation, none resulted in any significant change (Welford, 1966). Stated simply, Fitts proposed that if movements of average amplitude were speeded up then each movement could provide less information and, as a result, movement variability would be increased by a specified amount.

Crossman and Goodeve (Note 1) and later Keele (1968) put forward a theory to account for Fitts' findings. In this theory the authors proposed a system of movement control based on the continued monitoring of feedback information and the subsequent issuance of movement corrections. However, research aimed at examining movement patterns for evidence of corrections was equivocal. Annett, Golby and Kay (1958) and Brown and Slater-Hammel (1949) demonstrated the presence of movement corrections, while Langolf, Chaffin and Foulke (1976), in a microminiature task, failed to uncover evidence of within movement corrections. Furthermore, the theory of feedback control could not accomodate movements which were completed within a simple reaction time. Such rapid movements allowed insufficient time for processing of feedback information and the subsequent issuance of corrections based

on this information (Hick, 1952; Welford, 1952; Schmidt, Zelaznick, Hawkins, Frank and Quinn, 1979).

Howarth and Beggs (1970) and Beggs and Howarth (1972) proposed a visually mediated intermittent feedback mechanism as the basis for the control of aimed movements. They proposed that the error on target was related to the velocity of limb movement during the terminal phases of the movement. Error on target was thought to be proportional to the distance from the target at which the last correction was made. However, the theory was equally unable to account for movements completed within one reaction time.

Schmidt et al (1978, 1979) proposed an alternate theory based on the observation that the motor system appears to be contaminated by noise, (within subject variability). They proposed that this variability was related to parameters of the movement i.e. amplitude and speed. Central to the theory was the notion that movements could be centrally organized by a motor program which, when executed, could complete a movement without the involvement of peripheral feedback.

The Schmidt theory related the variability in target accuracy, effective target width (W_e), to the within subject variability of velocity, at the end of acceleration. Schmidt reasoned that if movement velocity was directly proportional to the magnitude of the impulsive forces, then variability in movement velocity must also be proportional to the variability of the impulsive forces. Therefore, as movement velocity increased, variability in the magnitude of the impulsive force and the time over which the force was acting also increased. This resulted, according to Schmidt, in greater error in

achieving the aimed for target.

The basic statement of the model is given by:

$$W_e \propto A/MT$$

This formulation seems to describe rapid movements (less than 200 msecs duration) but cannot account for slower movements of longer duration. The lack of a single formula which accomodated both rapid and slow aiming movements prompted Klapp (1975) to suggest that movements of long duration were under feedback mediated control, while rapid short duration movements required control by motor programs.

Much evidence favoring the central control of movement was based on the observation that responses to feedback information were often in excess of the duration of many movements (Lashley, 1951; Keele, 1968; Glencross, 1975, 1977; Keele & Posner, 1968). Lenneberg (1967) argued that the many hundreds of coordinated muscular movements required in the production of a relatively few seconds of speech could not be under feedback mediated control. Taub and Berman (1968) studied the performance of gross movements in rhesus monkeys following deafferentation of the monkey's limbs (surgical elimination of afferent feedback). Taub and Berman found that monkeys could use deafferented limbs in a reasonably coordinated manner following deafferentation. Laszlo (1967, 1968, 1969) duplicated the results of Taub and Berman in human subjects by employing ischemic nerve block techniques. However, doubts about the complete efficiency of such techniques (Glencross & Oldfield, 1975) cast doubt on the importance of such research.

While much evidence has been cited to favour centrally programmed

control of movement, the importance of feedback information cannot be discounted. Smith (1962) reported that deafferented specimens could make only jerky uncoordinated movements in the absence of feedback information. Fine graded manipulative movements were not possible. Glencross (1975) believed that even centrally generated movements must be integrated with peripheral sensory information at some stage of execution.

In order to examine possible programmed features of movement Kelso, Southard and Goodman (1979) employed a simultaneous two handed movement paradigm. They found that movement time was common to both hands (as measured by between hands correlation) while movement amplitude and height were independent. They postulated that movement time was a programmed feature of movements. Using a related procedure Schmidt et al (1979) demonstrated that only 1% of variability in movement endpoint (a measure of spatial accuracy) could be associated with incorrect program selection. However, high degrees of variability were related to selection of particular parameters. A high correlation between effective target width and the magnitude of the accelerative impulse supported the theory that impulse variability was a major determiner of W_e.

Schmidt et al proposed that movements could be programmed in advance and that certain parameters of the program specified the magnitude and duration of the accelerative impulse. Such a theory would predict that if a mass was added to a limb following the initiation of a programmed rapid movement that the limb would fall short of the aimed for target. This would be due to the inability of

the system to modify the parameters of the program until the movement had been completed. Damaging evidence to this position was presented by Bizzi, Polit and Morasso (1976); Bizzi, Dev, Morasso and Polit (1978) and Polit and Bizzi (1979). Examining movement control in normal intact and deafferented monkeys they demonstrated that addition of mass to a limb following initiation of a movement did not alter the accuracy of the movement in either normal or deafferented specimens. Furthermore, displacement of the limb prior to the initiation of the movement did not affect the resultant accuracy of intended movement in deafferented specimens, even if the displacement carried the limb beyond the target.

It was subsequently proposed that the endpoint of the movement was achieved by the specification of a set of length and tension parameters in agonist and antagonist muscle groups. These defined an equilibrium point between agonist and antagonist muscles which correctly positioned the limb in relation to the target. This "mass-spring" view of movement control was first proposed by Bernstein (1967) and later by Crossman and Goodeve (1963). It can be interpreted as a system which displays von Bertallanfy's (1973) principle of equifinality.

While damaging to the Schmidt theory Bizzi et al (1976, 1978) and Polit and Bizzi (1979) viewed the mass-spring as the means of achieving end point location. They suggested that a number of processes, acting in parallel, are responsible for the overall performance of aiming movements. One such process, it was suggested, would be responsible for control of limb velocity. Falkenberg and Newell (1980)

demonstrated that average velocity may be a programmed feature of movement. This gives rise to the possibility that the Schmidt et al theory may only speak to the control process underlying limb velocity.

The Fitts formulation was concerned with the outcome of performance and its relation to the parameters of the movement. The main emphasis was an examination of the outcome of behavior. The Schmidt theory, however, was concerned with identifying underlying control mechanisms of movement and as such was more process oriented. The two theories, while often taken as opposite views of the same problem, can be seen to be completely different in approach and application. The following experiments were designed to examine the fundamental differences between the Fitts (1954) and Schmidt et al (1978, 1979) formulations.

Examination of the reciprocal tapping tasks of Fitts and the single rapid aiming tasks of Schmidt et al resulted in the following differences being identified:

1. In the Fitts' task the independent variables were movement amplitude and target width, while movement time and error rate were dependent variables. In the Schmidt et al paradigm the independent variables were movement amplitude and movement time, while effective target width was the single dependent variable.
2. The reciprocal nature of the Fitts' task confounded errors on tap n with errors on tap n-1, and the impulse for stopping tap n-1 was the same as that for

starting tap n. Further, visual feedback was used in responses to an unknown degree and changed with the accuracy requirements of the task.

3. The Fitts' task required the subject to attend to two targets, whereas the Schmidt tasks required subjects to monitor only the movement endpoint. As such, the Fitts' task was bi-phasic in nature and the Schmidt tasks uni-phasic.

It is proposed that the variable application of the Fitts and Schmidt et al formulations may have been due to fundamental task differences which existed between the bi-phasic reciprocal tapping task and the uni-phasic single aiming movement. It is further proposed that such differences were attributeable to differential attentional demands of the tasks. Reciprocal tapping involved the monitoring of two targets separated by some distance and thus required the switching of attention between targets. Single aiming, however, involved no peripheral monitoring and consequently all available capacity could be devoted to target acquisition.

The following experiment tested the null hypotheses that, no differences in the means of measured parameters of movement existed as a result of the nature of the uni-phasic and bi-phasic differences between single aiming and reciprocal tapping movements respectively, and, that no differences in the variability of the measured parameters of movements existed as a result of the previously described differences between single aiming and reciprocal tapping tasks.

EXPERIMENT I

An examination of the Fitts and Schmidt methodologies was conducted in order to determine which dependent variables might be used when comparing the two approaches. Appendix 1 (review of literature) gives a review of the Fitts and Schmidt formulations.

In the Schmidt experimentation the single dependent variable was effective target width (W_e). The theory of motor output variability was based, however, on a theoretical relationship between W_e and the magnitude and duration of the accelerative impulse producing the move. Schmidt proposed that variability in target accuracy at a given distance was a result of variability in the time and force production mechanisms in the accelerative phase of movement. The Schmidt methodology unfortunately did not assess either the impulse magnitude or the duration of the decelerative phase of movement. His results and interpretations were based almost completely upon those forces propelling the limb, and not those related to its deceleration. A full examination of the Schmidt methodology resulted in the identification of a number of alternate dependent variables. These were: duration of accelerative impulse and its associated variability, duration of decelerative impulse and its associated variability, magnitude of accelerative impulse and associated variability, magnitude of decelerative impulse and associated variability, and effective target width (W_e).

Examination of the Fitts methodology resulted in the addition of movement time to the list of dependent variables under consideration.

A question of fundamental importance in understanding movement control involves the relationship between initiation and execution

stages of movement. Fitts and Peterson (1964) suggested that perceptual and motor processes could be considered as being independent of each other. Consequently the time required to initiate movement (reaction time minus stimulus processing time) was unrelated to the required accuracy of the movement. Movement time on the other hand, varies according to the required accuracy of movement. Crossman and Goodeve (Note 1) and Keele (1968) attributes this increase in movement time to an increase in the number of within movement corrections that could be required to achieve smaller targets.

The Crossman and Goodeve (Note 1) and Keele (1968) theories depended on the monitoring of sensory feedback. Schmidt supported the notion that whole movements could be organized or programmed in advance and executed without need for feedback information. Furthermore rapid single movements could be completed in times short enough (i.e. less than 200 msecs) to prevent the utilization of feedback information. More exacting movements, such as aiming movements requiring higher degrees of accuracy, could require a more precise program. Initiation time would therefore increase with the increased accuracy demands. Henry (1960) was able to demonstrate that initiation time did in fact vary in response to movement complexity. Further, Glencross (1972), and Norrie (1974) demonstrated that movements requiring a pause and reversal of direction on a definite target, in route to a final target require longer initiation times than simple forward movements. Reaction time was therefore added as the final variable of interest to be used in the comparison between single rapid aiming and reciprocal tapping movements. The former

being considered to be programmed in advance and the latter dependent upon feedback information for error correction.

The eight dependent variables in the following experiment were: reaction time, duration and variability of accelerative impulse, duration and variability of decelerative impulse, magnitude and variability of accelerative impulse, magnitude and variability of decelerative impulse, distance moved prior to correction, i.e. a standard deviation specifying the target width (W_e), distance moved following correction, and total movement time.

In order to compare the Schmidt and Fitts' formulations the following movement conditions were established which differed only in their mode of initiation. Condition One; involved a simple reaction time task followed immediately by a rapid aiming movement to a specified target. The reaction time task was used to control the subject's attention by forcing him to attend to an auditory stimulus. In Condition Two, a reciprocal aiming task was developed which required a single movement away from the body mid-line to a peripheral target; followed immediately by a rapid return aiming movement to acquire a specified target. This second phase of the reciprocal aiming task was considered to be identical to the rapid aiming movement specified under the first condition. A single rapid aiming movement, without a preceding reaction time task was used in Condition Three. The subject initiated the movement when he felt prepared to do so.

These three conditions were established for the following reasons. Conditions One and Three were identical single aiming movements of the Schmidt variety which differed only in their demands

on attention. Condition One required attention to be directed towards an auditory stimulus while Condition Three did not. A comparison of these movements was in effect a comparison based upon differences in attention demands of each condition. Condition Two a Fitts type of task; embodied both the rapid aiming movements used in Conditions One and Three and an initial outward movement to a peripheral target; an important feature of reciprocal tapping. This condition required attention to be directed towards a peripheral physical stimulus and also a planned reversal of movement direction.

The three established conditions described a continuum of movement requirements. Condition Three, a single rapid aiming movement with no demand on attention, Condition One, a single rapid aiming movement with some demand on attention, and Condition Two, a rapid aiming movement following a planned reversal of movement direction requiring attention to be directed towards a physical stimulus which coresponded to the point at which the planned reversal had to take place.

The three conditions embodied all of the features of single aiming and reciprocal tapping movements allowing a comparison of such movements to be conducted.

Method

Subjects

Thirty male subjects, students at the University of Alberta, ranging in age from 19 to 32 years, volunteered for the experiment. All subjects wrote with their right hands.

Apparatus and Task

A PDP 11/10 computer was employed to control the experiment and collect data. The interaction between the apparatus and computer is shown in figure 1. The computer was used to control an auditory tone which acted as an event indicator to the subjects. The tone was activated by the computer by closure of a solid state switch via a signal from the computer's digital to analog converter. This switch activated an EICO audio wave generator to produce the tone. The computer was also employed to collect analog data from an accelerometer and potentiomater. These devices were connected to the A/D (analog to digital) channels of the computer. Analog data was subsequently digitized and stored on floppy disks.

Three target lights, Leecraft 3200 amber snaplights, were embedded in a plywood board which was first covered with heavy black paper and then overlayed with ¼ inch household window glass. The effect was to give three target lights which appeared as orange strip lights approximately 0.2 cm in width. The three lights were separated from a 1 cm wide metal start plate by distances of 10, 20 and 40 cm respectively. The three target lights could be individually controlled by the experimenter.

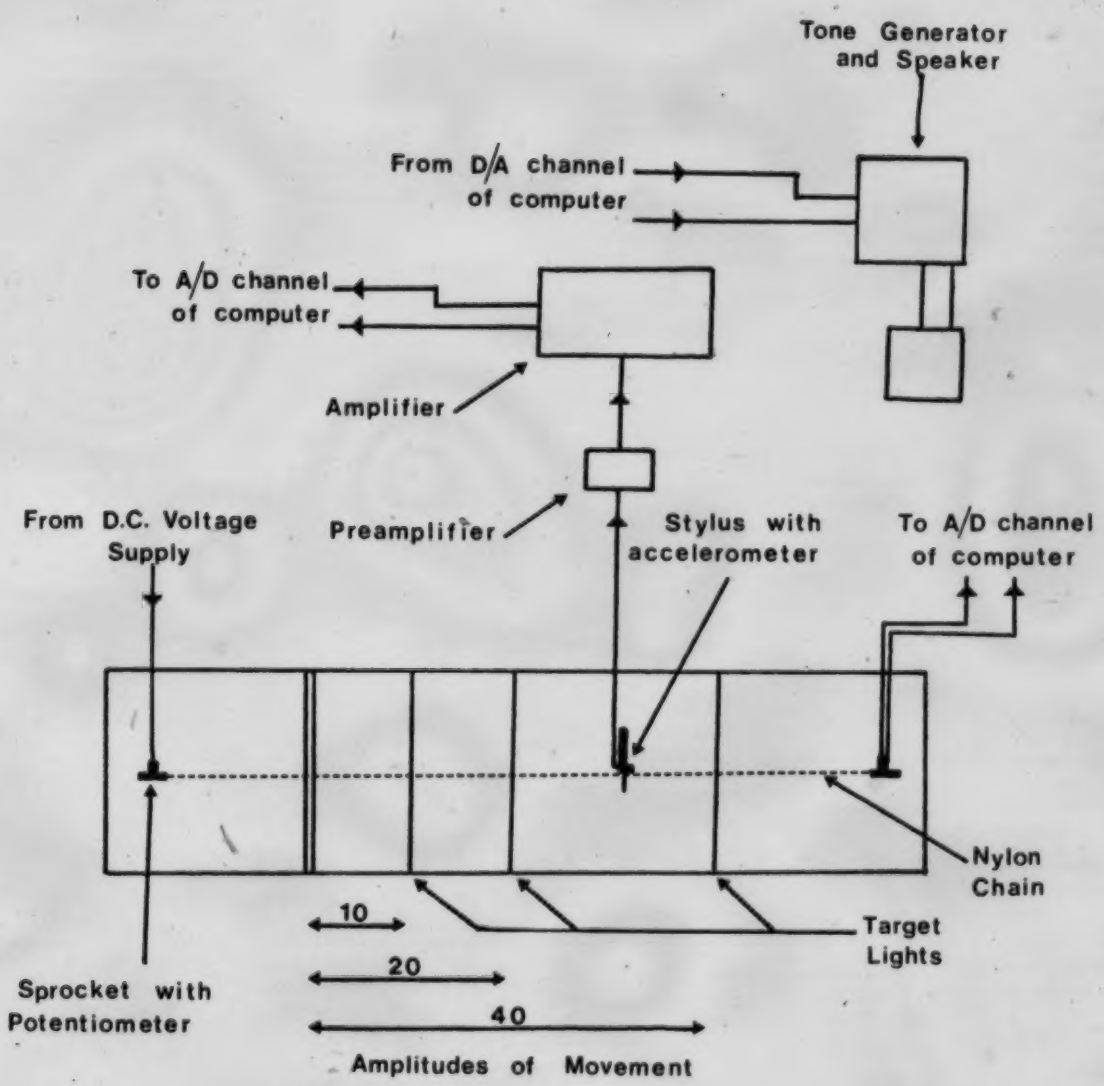


Figure 1. Plan of Apparatus and Interface with Computer

Two lightweight brass sprockets were mounted individually upon the spindles of two 10 Kohm ten turn potentiometers. The potentiometers were mounted on the table 100 cms apart from each other. They were situated centrally over either end of the plywood board. The potentiometers were mounted on uprights approximately 5 cm above this board allowing it to move freely beneath them. An Eveready heavyduty 6 volt battery was connected to the potentiometers. Only the output of one of the potentiometers was used as a source of analog signal for transmission to a digital channel of the computer.

A continuous nylon ladder chain ran between the two brass sprockets. Linear movements of the nylon chain caused rotation of the potentiometer spindles and a resultant change in resistance. Since the potentiometers were linear, movement of the nylon chain caused linear changes in output voltage. These changes in output voltage were sampled at a rate of 500 values per second.

A metal stylus, approximately 15 cm in length was fixed to the lower segment of the nylon chain. A piezoelectric accelerometer (Bruel and Kjaer Type 4332) was mounted on the stylus. The accelerometer was attached to a preamplifier (Bruel and Kjaer, Type 2616) which was mounted on the back of the subject's chair at the level of the shoulder. Output from the preamplifier was fed to a power amplifier (Hewlett Packard Type 467A). Output from that amplifier was then fed into a second A/D channel of the computer. Movements performed by displacing the stylus in the lateral plane, were therefore converted into voltage equivalents by the accelerometer and potentiometer and then digitized by the computer for immediate storage and eventual

analysis.

An inclined wooden screen was fitted to the bench on which the equipment sat. The screen was of such length as to prevent subjects from viewing their arms or the equipment to the right of a line drawn perpendicular to the subject's mid-line. Since target lights could be illuminated individually and the position of the plywood board adjusted freely, the experimenter could make the target light visible to the subject while at the same time obscuring the start plate and right limb. Target lights coresponding to the amplitude of movement desired could be illuminated and correctly positioned by the experimenter relative to both screen and subject.

The task in Condition One required the subject to respond to an auditory signal by performing a single rapid aiming movement in the lateral plane. The movement, from initiation to target acquisition, was to be completed as rapidly and accurately as possible following the tone.

The subject was seated approximately eight inches from the bench such that the mid-line of the subject's body was directly opposite the target light. The metal stylus was fitted to the subject's right hand by taping it between the index and forefingers. The stylus was then attached to the nylon ladder chain and the subject positioned its tip on a cross point embossed into the metal start plate. The subject was allowed to view beneath the screen to acquire the cross point but following this was instructed to return to an upright position, in which only the target light was visible.

The computer was programmed to give a clearly audible tone of

500 msecs duration signifying that a trial could begin. When the subject felt he was ready he depressed a small switch with his left hand. After a three second delay following depression of the switch the computer gave a second long tone of 500 msecs duration which, the subject was instructed, was a warning tone. The computer was programmed to create a random delay of between 500 and 3,500 msec following the warning tone. Following this delay the computer gave a signal of 50 msec duration which was the subject's signal to initiate his response. The subject was previously instructed that upon receiving this signal he was to move as rapidly and accurately as possible from the start plate to come to rest above the illuminated target without coming into contact with the glass.

On initiation of the signal tone the computer was programmed to sample and store the incoming data from the accelerometer and potentiometer. Sampling occured asynchronously at a rate of 1000 samples per second. Sampling lasted for 1000 msec, thereby providing 500 samples from the accelerometer and 500 from the potentiometer. Following a variable delay not exceeding 8000 msec during which acquired data was stored by the computer, the above procedure was repeated again. Subjects were given ninety such trials,divided into sixty training trials followed by thirty test trials.

The task in Condition Two required the subject to perform a rapid aiming movement to a target following the acquisition of a second target situated to the subject's right. The aiming movement required the subject to return, as fast and accurately as possible to the start position following the acquisition of the second target.

Subjects in Condition Two were seated as in Condition One and the stylus taped between the index and forefingers of the right hand. The subject began a trial by positioning the sylus on the glass directly on the target light. Following a 500 msec tone from the computer, the subject moved the stylus along the glass to the right until a change of context was perceived indicating contact with the start plate (this change of context was extremely obvious to the subject). Contact with the start plate was the signal that the subject was to move as rapidly and as accurately as possible back to the target light without contacting the glass.

The metal start plate and stylus were so arranged that contact between the stylus and the plate acted as the closure of a switch. Upon closure of this switch the computer began to sample for 1000 msec from the accelerometer and potentiometer. Following a delay during which sampled data was stored by the computer a second tone of 500 msec duration was given indicating the start of a new trial. Subjects were again given sixty training followed by thirty test trials.

The task in Condition Three required the subjects to perform a single rapid aiming movement to an illuminated target. This movement was self initiated by the subject.

Subjects were seated as in Conditions One and Two, with the stylus once again taped between the index and forefingers of the subject's right hand. The subject positioned the stylus so that it rested lightly upon the metalic start plate. The subject was allowed to view beneath the screen to position the stylus correctly, but

once this was completed the subject was instructed to return to an upright position in which only the target light was visible. The computer was programmed to give a 1000 msec tone indicating that a trial could commence. The subject initiated a trial by pressing the stylus down firmly upon the metalic start plate. This action closed the switch lying beneath the start plate and caused the computer to commence sampling. The subject then moved as rapidly and accurately as possible to stop above the target light without coming into contact with the glass. Following a variable delay period not longer than 8000 msec during which sampled data was stored by the computer, a second tone of 1000 msec was given to indicate that a further trial could begin. Subjects were given sixty training followed by thirty test trials.

Ten subjects were randomly assigned to each treatment condition. Subjects in each condition were tested under all amplitudes, namely 10, 20, and 40 cm. The order for testing for amplitude was decided randomly, however, once this order was decided all subjects were tested in this order. The order for testing for amplitude was 20 cm, 10 cm, and 40 cm. The thirty subjects were tested at their convenience. Subjects were, however, tested only once per day to avoid fatigue effects.

Design

10 subjects were randomly assigned to each of the three treatment conditions, Condition One, Condition Two, and Condition

Three. Results were analysed using a three way factorial repeated measures design. The number of levels of the three factors were; 3 (treatment condition) X 3 (amplitude of movement) X 20 (trials). Following this analysis standard deviation data for each subject performing under each amplitude of movement were submitted to a two way factorial repeated measures analysis of variance. The number of levels of the two factors were; 3 (treatment condition) X 3 (amplitude of movement).

Data Analysis

On completion of the 30 test trials the computer indicated the end of the test session by giving four short tones. The computer was further programmed to analyse the stored digital data. Appendix B gives a graphical representation of the digital data collected during a single trial. The diagram shows how this data was used to obtain measures on the dependent variables of interest. Data from the potentiometers was used in the calculation of displacements and gave, therefore, distances moved prior to and following corrections. The accelerometer was used in the calculation of the magnitudes and durations of the impulsive forces as well as total movement time.

Only the first 20 acceptable trials from each test session were submitted to statistical analysis. Trials were considered to be unacceptable for the following reasons; responses were initiated prior to the required signal, movements were completed after the end of the computer sampling period and were not, therefore,

completely sampled, subjects failed to respond to the signal, movements were performed at such speed that they failed to provide suitable acceleration data for analysis by the computer, these movements were not felt to have been performed as fast as possible.

Results and Discussion

Table 1 is a summary of the results of the three way factorial repeated measures analysis of variance performed on data obtained for each of the dependent variables in Experiment One. Table 2 is a summary of the results of the two way factorial repeated measures analysis of variance performed on standard deviation data obtained from Experiment One. For the purposes of the current discussion major consideration will be given to the variables of effective target width (standard deviation of distance moved prior to correction), variability of impulse duration (standard deviation of duration of accelerative impulse) and reaction time.

The major prediction of the Schmidt et al (1978, 1979) theory of motor output variability related variability of impulse duration to effective target width, W_e. The theory proposed that as variability in impulse duration increased there would be a proportional and linear increase in W_e. Examination of the results from the current experiment showed a significant main effect for treatment condition on the variable, variability of impulse duration, $F(2,27)= 7.74$, $p < .01$. No significant main effect for treatment condition was obtained for the variable, effective target width. For the main effect of amplitude, significant differences were obtained for the dependent variable effective target width, $F(2,54) = 1479.94$, $p < .000$, but no significant differences were obtained for variability of impulse duration.

Neither of these results would be predicted by the Schmidt theory. According to the theory, significant differences between

Table 1

F ratios obtained from the three way analysis of variance performed on raw data for each dependent variable of Experiment One.

Dependent Variable	Treatment Condition (C)	Amplitude (A)	C X A	Trials (T)	C X T	A X T	C X A X T
Reaction Time	22.00*	3.00	2.31	1.25	1.02	0.92	0.95
Time of Acceleration	5.94*	46.05*	0.69	0.97	0.72	1.08	0.81
Time of Deceleration	4.84*	8.21*	0.18	0.34	1.23	0.91	0.86
Distance moved prior to correction	0.93	1479.90*	0.18	1.25	0.91	1.15	0.11
Distance moved following correction	0.55	7110.10*	1.45	0.53	0.50	1.19	1.33
Magnitude of accelerative impulse	7.74*	60.32*	1.01	1.19	1.03	1.21	1.16
Magnitude of decelerative impulse	1.72	31.22*	0.21	0.56	0.79	0.84	0.77
Movement Time	4.95*	19.08*	0.54	0.57	1.01	0.71	0.96

* indicates probability < .05

Table 2

F ratios obtained in analysis of variance performed on standard deviation data for each dependent variable in Experiment One.

Dependent Variable	Treatment Condition (C)	Amplitude (A)	C X A
Standard deviation of duration of accelerative impulse.	5.83*	2.248	0.58
Standard deviation of duration of decelerative impulse.	4.90*	0.062	0.41
Standard deviation of magnitude of accelerative impulse.	2.04	9.482*	0.13
Standard deviation of magnitude of decelerative impulse.	1.37	4.981*	0.49
Standard deviation of distance moved prior to correction.	0.12	26.532*	0.95
Standard deviation of distance moved following correction.	0.23	20.926*	0.55

* indicates probability < .05

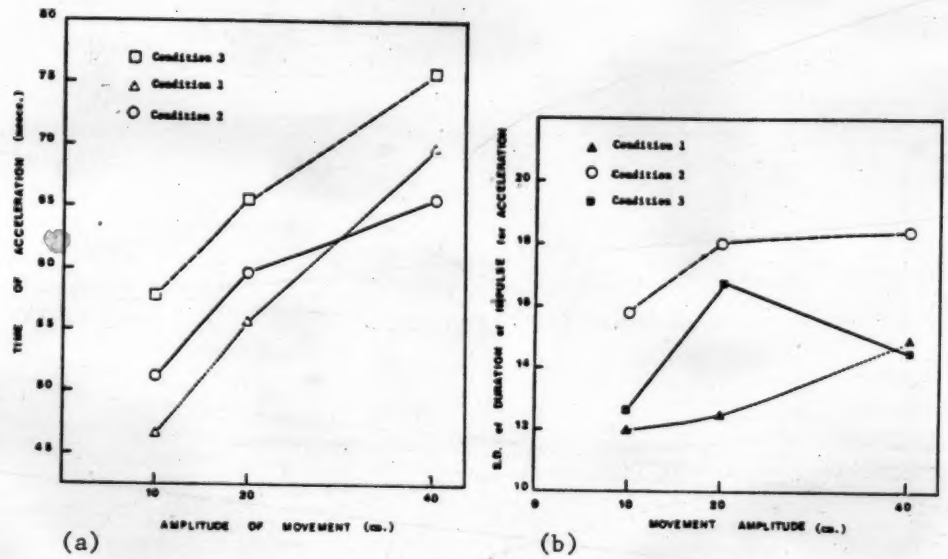


Figure 1. Mean (a) and standard deviation (b) of duration of accelerative impulse as a function of amplitude and treatment condition

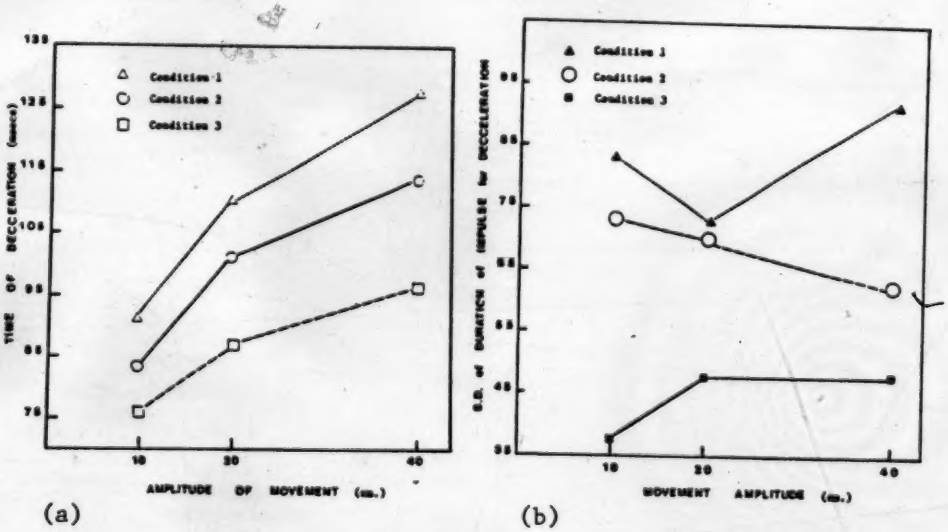
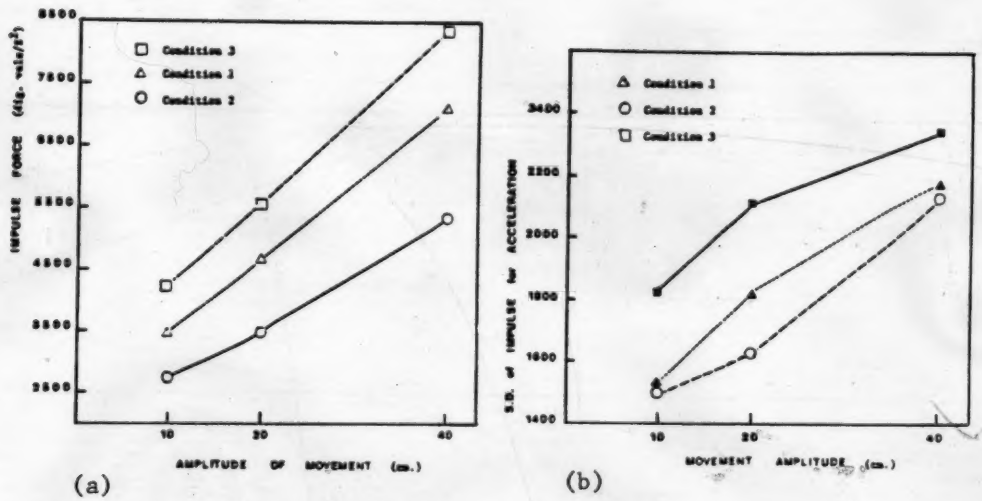
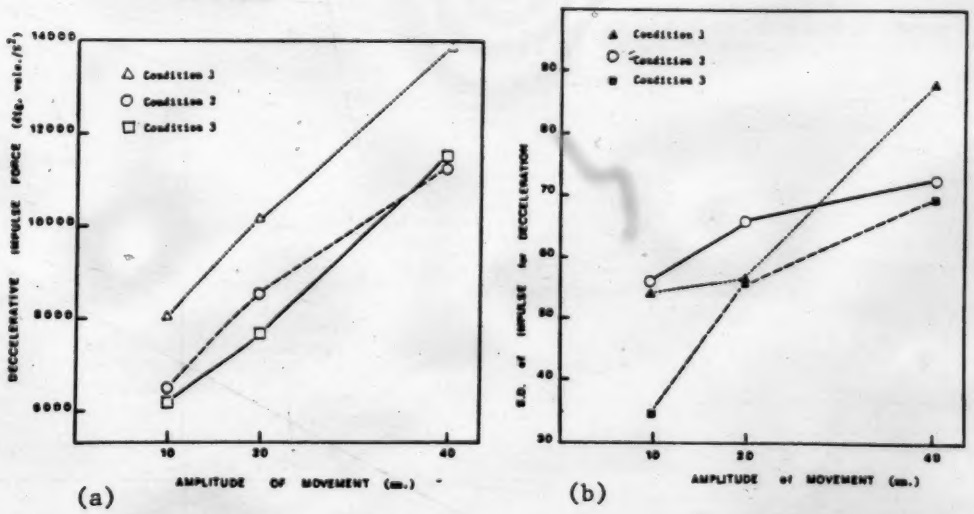


Figure 2. Mean (a) and standard deviation (b) of duration of decelerative impulse as a function of amplitude and treatment condition.



(a) (b)

Figure 3. Mean (a) and standard deviation (b) of magnitude of accelerative impulse as a function of amplitude and treatment condition.



(a) (b)

Figure 4. Mean (a) and standard deviation (b) of magnitude of decelerative impulse as a function of amplitude and treatment condition.

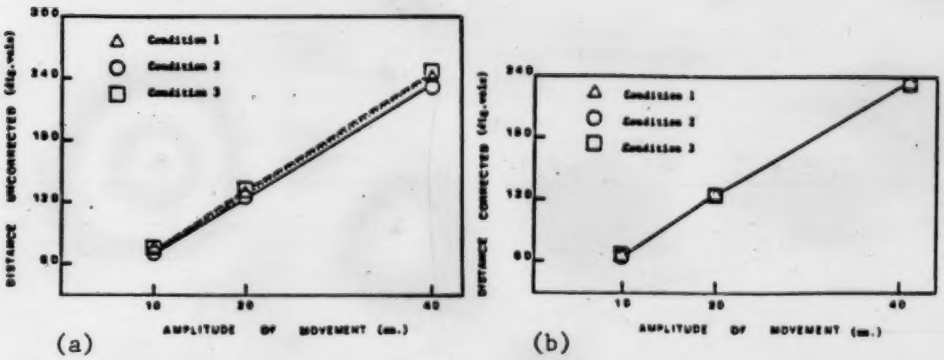


Figure 5. Mean distance moved prior to (a) and following (b) correction as a function of amplitude and condition.

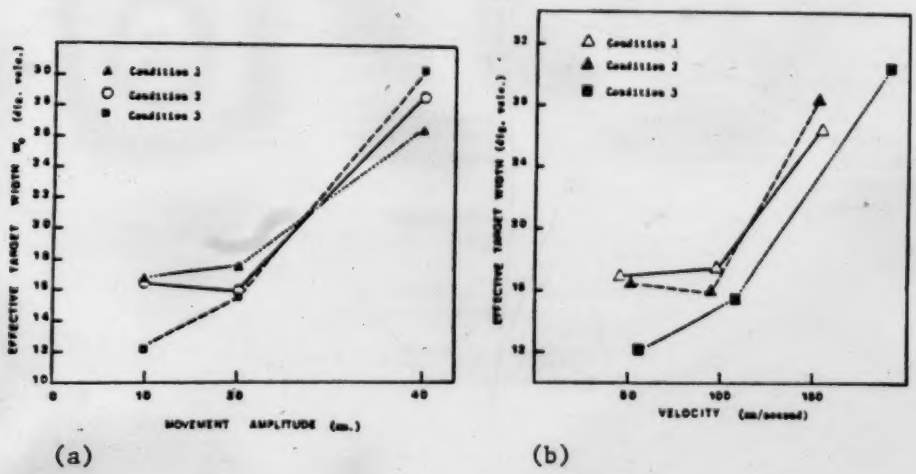


Figure 6. Effective target width as a function of movement amplitude and treatment condition (a) and movement amplitude and velocity (b).

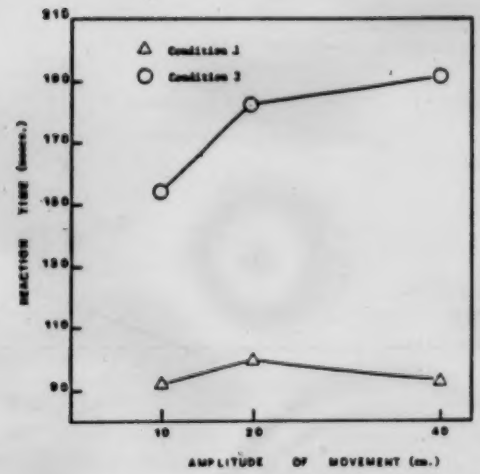


Figure 7. Reaction time as a function of amplitude for Conditions One and Two.

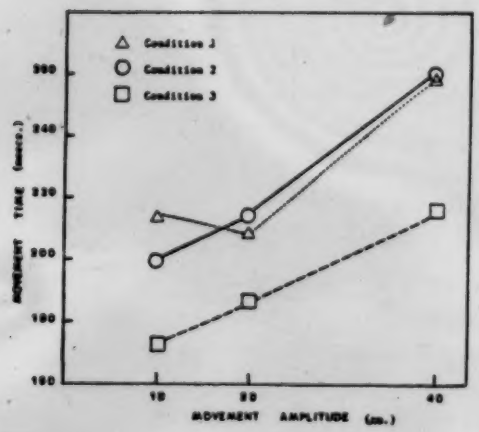


Figure 8. Movement time as a function of amplitude and treatment condition.

treatment conditions on the variability of impulse duration should have been accompanied by similar differences between treatment conditions for effective target width. Similarly within conditions, as amplitude increased, increases in effective target width should have been accompanied by a proportional increase in the variability of impulse duration. Neither of these results was obtained in the current experiment and therefore the experiment failed to support Schmidt's theory.

Fitts' (1954) theory predicted that as movements of a fixed amplitude were speeded there would be an increase in the variability of movement endpoint, W_e. Results of the current experiment demonstrated a significant main effect for treatment condition on the dependent variable movement time $F(2,27) = 4.95$, $p < .05$. Movements in the self-initiated condition (COndition Three) were performed significantly faster than movements in conditions One and Two. There was, however, no main effect for treatment condition on the dependent variable effective target width. This finding was contrary to the prediction of the Fitts' theory which would have required an increase in effective target width as movements became faster. It would appear in the current experiment that the mode of movement initiation affected the resultant accuracy and speed of movement. Self-initiated movements with limited attentional demands could be performed more rapidly than but with equal accuracy to movements requiring a response to a tone or a planned reversal of direction (Conditions One and Two respectively).

Figure 6(b) shows effective target width plotted as a function

of movement velocity and treatment condition. No significant increase in effective target width was observed when movement velocity increased from 50 to 100 cm per second. A significant increase in effective target width was observed when movement velocities increased from 100 to 150 cm per second. In the first case both amplitude and velocity of movement were increased with no significant increase in W_e. These results suggested that effective target width did not increase until subjects operated at velocities which put them above the capacity of the motor system. It could be suggested that single aiming movements could be performed at greater velocities than reciprocal movements while maintaining the same degree of accuracy because less capacity had to be devoted to the monitoring of stimulus events. It could be suggested that Fitts' law holds in conditions in which subjects are performing at or beyond the capacity of the motor system while the Schmidt formulation would hold under conditions where subjects were operating below capacity. The performance of single aiming movements which required attention to be directed towards an extraneous stimulus event should by the previous argument, closer approximate performance of movements requiring planned reversals such as those in Condition Two, than the self-initiated movements of Condition Three. While insufficient data points are available figure 6 (b) lends some support to the previous argument. Condition Three (self-initiated single rapid aiming movement) demonstrates a near linear increase in effective target width with movement velocity while Conditions One and Two may well demonstrate logarithmic increases in effective target width with movement velocity.

The foregoing discussion is based on the assumption that within treatment conditions requiring response to a stimulus (Conditions One and Two) there was no trade off between complexity of movement, as represented by amplitude of movement, and reaction time. Henry et al (1960) proposed that the time required to program a movement, as reflected by reaction time, increased as the complexity of the movement increased. Analysis of variance performed on reaction time data from the current experiment showed no significant main effect for amplitude. Subjects did not take longer to plan movements of greater amplitudes. Data obtained for other dependent variables could not be attributed to subjects adopting a trade off strategy in which programming time was increased for longer amplitude movements. Observed differences on the dependent variables measured could more safely be attributed to the experimental manipulation which required attention to be directed towards particular stimulus events.

A significant main effect for treatment condition was obtained for reaction time $F(2,27) = 22.0$, $p < .05$. Reaction times for Condition Two were significantly longer than those for Condition One. Henry et al (1960) would suggest that this reflected the greater complexity of movements requiring a planned reversal of direction. This increased reaction time did not result in a more complete programming of the return aiming movement. Figure 5 (a) and (b) show that increased planning time in Condition Two did not result in greater accuracy of movement. Analysis of variance showed no significant main effects or interactions for the variables distance moved prior to correction or distance moved following correction.

Figure 3 (a) and (b) show the magnitude and variability of impulse for acceleration. Condition One shows greater accelerative impulse with greater associated variability than condition two. This is reflected in a significant difference obtained in analysis of variance for the dependent variable movement time for the main effect of treatment condition, $F(2,27) = 4.95$, $p < .05$. A similar result was obtained for the dependent variable decelerative impulse force. A significant main effect was obtained for the main effect of amplitude $F(2,54) = 31.22$, $p < .05$. Figure 4 (a) shows near linear increases in decelerative impulse for all conditions as a function of amplitude of movement. While no significant main effect for treatment condition was obtained it was interesting to note that Condition Three while demonstrating the largest accelerative impulses (figure 3) demonstrated the smallest decelerative impulses. This may be due to the more complete programming which may have taken place because no attention was required to be directed to any extraneous events. Figures 1 and 2 show that not only was the magnitude of accelerative impulse greatest for Condition Three it acted over the longest time of the three conditions while the decelerative impulse as well as being the smallest of all conditions also acted over the shortest time. These two results also seem to support the notion that more complete programming took place for movements performed by subjects in Condition Three.

In conclusion, the current experiment provided evidence to support the theory that single aiming and reciprocal tasks differ in their organization. The differences would appear to be related to the discrepent attentional demand between the three movement classes

examined. One explanation would be that increased demands on attention resulted in decreased capacity for movement programming. The effect on programming of decreased capacity was not reflected in increased variability of movement endpoint. Accuracy of movement was maintained in all conditions while parameters related to movement velocity were effected. It would appear that rapid movements can be performed with the same accuracy as slow movements providing the attentional demands in the slow movement case were severe. If this was the case then the performance of reciprocal tasks such as those in Condition Two should vary according to the demands placed on attention by the task. As the attention demanded by the point of reversal is increased, perhaps by making the target plate at that point narrower, then the characteristics of the return aiming movement should be altered. According to the foregoing argument these changes should not be related to the effective target width, effective target width should be maintained for movements of equal amplitude regardless of demands placed on attention. Rather, the effect should be noted on parameters relating to the velocity of the movement. A second experiment was conducted to examine and test this prediction.

EXPERIMENT 2

Experiment One provided some evidence to support a tentative theory that single rapid aiming tasks and tasks of a reciprocal nature differed in their organization. The observed differences in the measured parameters between the two classes of movement appeared to be dependent upon the amount of attention subjects were required to direct towards events other than the aiming response. Acquisition of the peripheral plate in Condition Two and attending to the stimulus tone in Condition One appeared to demand capacity. Reductions in the capacity available for formulating the movement response did not lead to a reduction in accuracy of movement. Rather, differences were observed in factors relating to speed of movement. It was subsequently suggested that Fitts' law may hold under conditions in which subjects are required to operate beyond the limited capacity of the human motor system. Similarly it was proposed that the Schmidt formulation held under conditions in which the subjects operated below the limited capacity of the motor system.

The foregoing argument suggested that in reciprocal tasks subjects were required to attend to targets which marked the points of reversal in the movement task. Because attention was demanded by the points of reversal, reduced processing capacity was available for the formulation of the subsequent response. The effect on performance was not reflected in a reduction in accuracy but rather in factors related to movement speed such as magnitude of accelerative impulse. It was proposed, therefore, that reduction in attention demanded at the points of reversal in a reciprocal task would result in movements of increased velocity but not increased accuracy.

Experiment Two was an attempt to manipulate the attention required to be directed to the points of reversal in an aiming task which required a planned reversal of movement direction. This was accomplished by manipulating the width of a peripheral target plate which represented the point at which reversal of the movement was required. It was hypothesized that as the width of the reversal plate increased so the subject would be required to devote less attention to its acquisition. Greater processing capacity would be available for planning and execution of the return movement following acquisition of the reversal point. The result of decreases in the attention devoted to the peripheral plate would be return movements of increased velocity. All movements, regardless of the attention demanded by the point of reversal, which was theorized to be dependent upon its width,would be performed with equal accuracy. It was further hypothesized that as demands on attention were reduced, performance of the aiming response in a reciprocal task would more closely approximate that of a single aiming response.

The question of interest in the current experiment related to the effect of attentional demand on performance of aiming movements requiring a planned reversal of movement direction. Performance was assessed by measurements obtained on the eight dependent variables detailed in Experiment One. Since attention demand in the task was thought to be dependent on the width of the plate representing the point of movement reversal, movements in the following experiment had to be visually guided.

Method

Subjects

Five male subjects, students of the University of Alberta, ranging in age from 21 to 29 years, volunteered for the study. All subjects wrote with their right hands.

Apparatus and Task

A number of modifications were made to the apparatus described in Experiment One. The screen which prevented subjects from viewing the course of movements was removed in order to allow for visually guided movements. The peripheral start plate which acted as the starting point for all movements was also removed. Three metal plates were constructed of widths 10, 20, and 40 mm respectively. These plates could be inserted by the experimenter into the position previously occupied by the peripheral start plate. When any of the plates were in position, the distance between the centre line of the plate and the three target lights remained 10, 20, and 40 cm. There were, therefore, nine possible combinations of peripheral target width (PTW) and amplitude of movement.

The task in Experiment Two required the subject to perform a visually guided single rapid aiming movement to a visually illuminated target following the acquisition of a metal plate situated to the right of the target light. This task required a planned reversal in movement direction at a predetermined point prior to the acquisition of the target.

A PDP 11/10 digital computer was used to control the experiment.

The interaction between the apparatus and the computer was identical to that described in Experiment One Condition Two. The computer was used to control an auditory tone which acted as an event indicator to the subjects. The tone was activated by the computer by closure of a solid state switch via a signal from the digital to analog channel of the computer. This switch operated an EICO audio wave generator to produce the clearly audible required tones.

The subject was seated for each test session as in Experiment One such that the mid-line of the subject's body was aligned with the target light. Prior to the arrival of the subject, the experimenter selected the appropriate amplitude of movement and width of peripheral plate and adjusted the equipment accordingly. The stylus, bearing the accelerometer, was taped between the index and forefingers of the subject's right hand. The stylus was attached to the lower segment of the nylon ladder chain and this arrangement allowed for movements only in the lateral plane. The subject was instructed that each trial would begin with the stylus resting lightly upon the target light.

The computer was programmed to give a long tone of 1000 msec duration to indicate that a trial was to begin. After a fixed period of 3000 msecs the computer was programmed to give a tone of 500 msec duration which acted as a warning tone. After a delay of 500 msec a very short tone of 50 msec duration sounded to indicate to the subject that the movement out to the peripheral plate was to begin.

Speed of movement out to the peripheral plate was controlled by a further tone which acted in metronome fashion. The subject was instructed that his movement to the peripheral target plate should

be evenly paced and in time with the pacing tone. This provided a relatively constant velocity of movement to the periphery for all amplitudes of movement since the duration of the pacing tone was proportional to the amplitude of the movement, 250 msec for 10 cm movements, 500 msec for 20 cm movements and 1000 msec for 40 cm movements. Upon initiation of the pacing tone subjects began the horizontal movement to the right towards the peripheral target plate.

Upon contact with the peripheral plate the subject was instructed to move as fast and accurately as possible to a position above the target light without coming into contact with the surface. Contact between the sylus and the peripheral plate acted as an event indicator to the computer. The computer commenced sampling data from the accelerometer and potentiometer for 1 second at a rate of 1000 samples per second.

Upon achieving the target the subject was instructed to remain there until the computer issued a further long tone indicating that the next trial would begin following a delay interval. During the delay the computer stored collected data for later analysis.

All subjects received 60 training trials followed by 30 test trials. Subjects were tested under all combinations of amplitude and peripheral plate size giving a total of 9 test sessions per subject. The order of testing for each subject was decided randomly by drawing the 9 combinations from a hat. Subjects were tested once per day for 9 days.

Design

The 5 subjects were tested under all combinations of amplitude and peripheral target width. Mean and standard deviation data were submitted to a two-way factorial repeated measures design with repeated measures on both factors. The levels of the two factors were; 3 (amplitude) X 3 (peripheral target width). Of the 30 test trials the first 20 acceptable trials were submitted for analysis. A trial was considered unacceptable for the following reasons; the subject failed to make contact with the peripheral plate, the subject failed to complete the aiming response within the sampling time of the computer, movements were performed at such speed that they failed to provide suitable acceleration data for analysis by the computer, these movements were not felt to have been performed as fast as possible, the subject failed to respond to the pacing tone and did not move to the periphery.

Table 3

F ratios obtained from analysis of variance performed on mean data obtained for each dependent variable in Experiment Two

Dependent Variable	Amplitude (A)	Peripheral Target Width (PTW)	A X PTW
Reaction Time	2.10	1.129	1.816
Duration of accelerative impulse	18.915*	5.985	1.344
Duration of decelerative impulse	7.029*	1.137	2.820
Movement Time	5.213*	1.232	0.578
Magnitude of accelerative impulse	45.920*	2.789	1.481
Magnitude of decelerative impulse	6.864*	1.746	3.252*
Distance moved prior to correction	159.290*	3.102*	2.928
Distance moved following correction	239.430*	1.813	2.403

* indicates probability < .05

Table 4

F ratios obtained from analysis of variance performed on standard deviation data obtained for each dependent variable in Experiment Two

Dependent Variable	Amplitude (A)	Peripheral Target Width (PTW)	A X PTW
Standard deviation of duration of accelerative impulse	1.276	2.375	2.039
Standard deviation of duration of decelerative impulse	5.539	1.746	2.215
Standard deviation of magnitude of accelerative impulse	4.680*	3.47	1.87
Standard deviation of magnitude of decelerative impulse	6.53*	1.16	2.24
Standard deviation of distance moved prior to correction	11.960*	5.05*	2.44

* indicates probability < .05

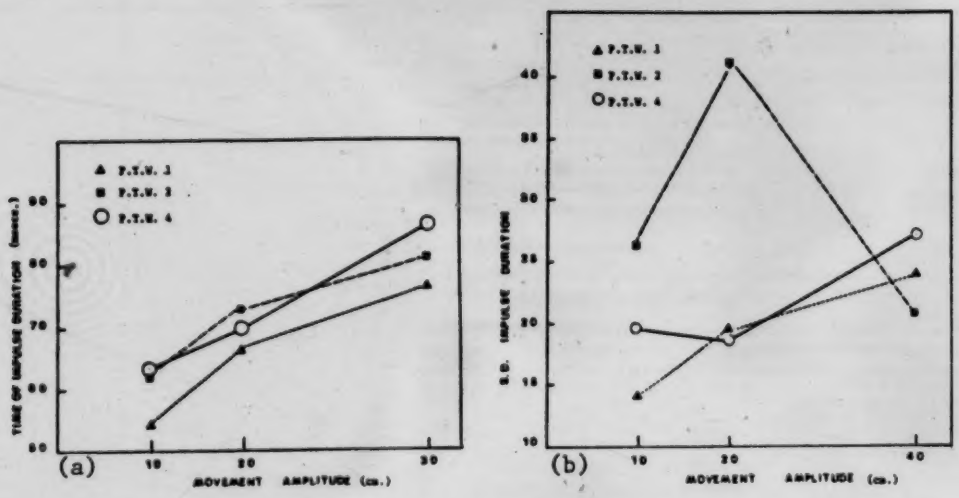


Figure 9 Mean (a) and standard deviation (b) of the duration of impulse for acceleration as a function of amplitude and peripheral target width (PTW).

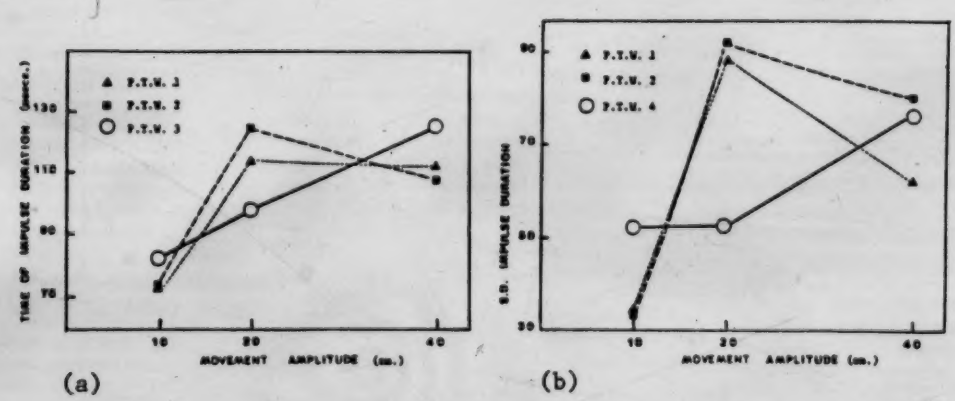


Figure 10 Mean (a) and standard deviation (b) of the duration of impulse for deceleration as a function of amplitude and peripheral target width.

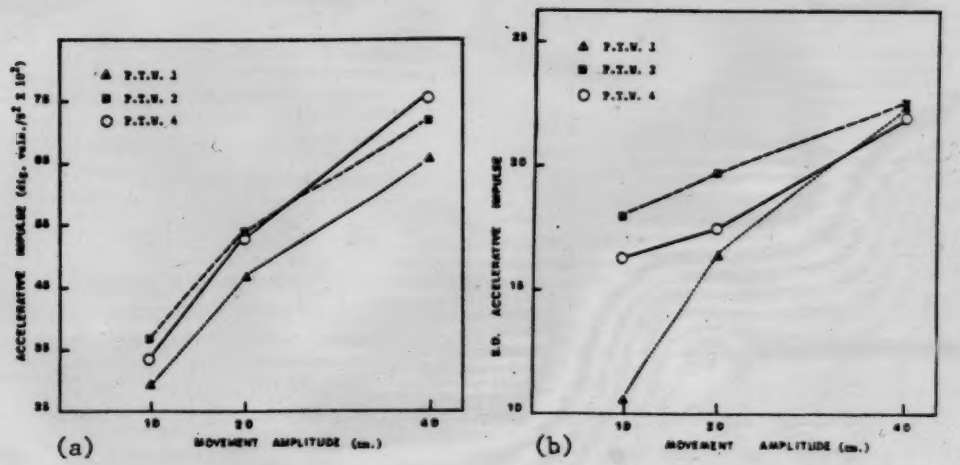


Figure 11 Mean (a) and standard deviation (b) of magnitude of impulse for acceleration as a function of amplitude and peripheral target width.

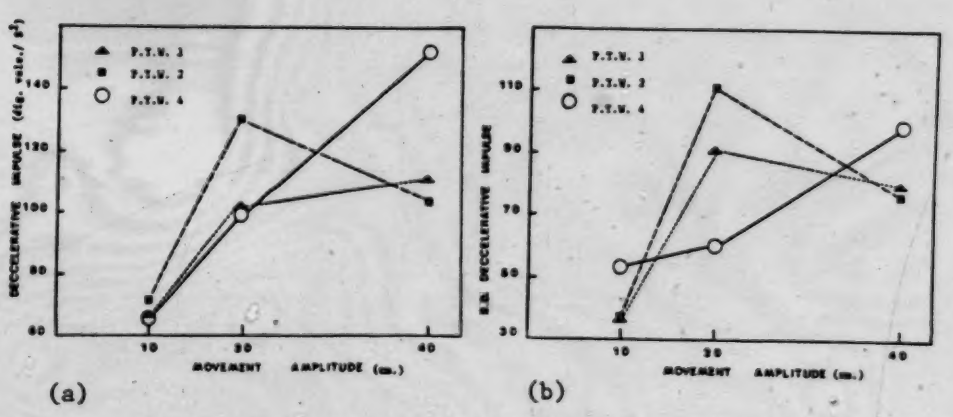


Figure 12 Mean (a) and standard deviation (b) of magnitude of deceleratives impulse as a function of amplitude and peripheral target width.

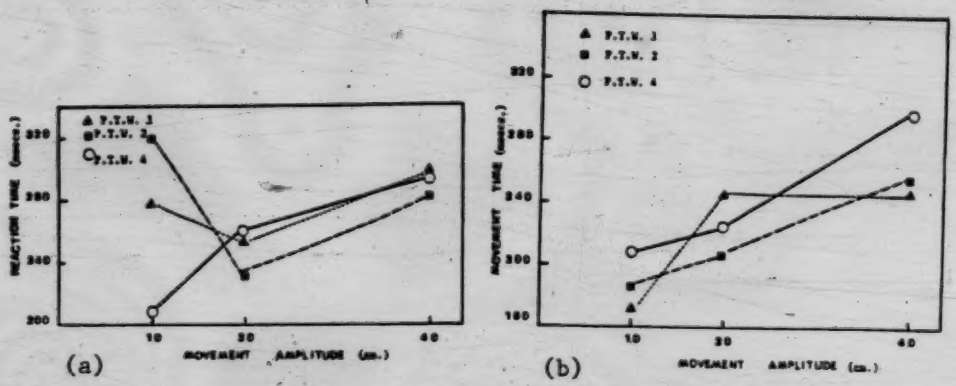


Figure 13 Reaction time (a) and Movement time (b) as a function of amplitude and peripheral target width.

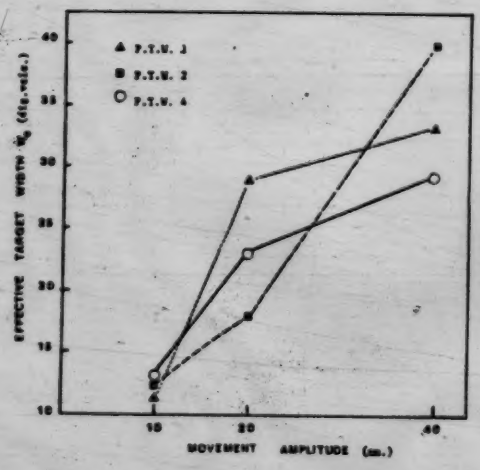


Figure 14 Effective Target Width as a function of amplitude and peripheral target width.

Results and Discussion

Tables 3 and 4 show the results of the two-way factorial repeated measures analysis of variance performed on mean and standard deviation data obtained from Experiment Two.

Figure 7 shows reaction time data for Conditions One and Two of Experiment One. The significant main effect of treatment condition was taken as an indication of differences in task complexity between Conditions One and Two. Henry (1960) and Klapp (1975) reported that more complex movements required increased processing time. In the current experiment no significant main effect or interaction was obtained for the dependent variable reaction time. For movements of fixed amplitude the manipulation of peripheral target width appeared not to increase the complexity of the response. The expected effect on attention of reducing the width of the peripheral plate did not take place.

Figure 14 presents effective target width (standard deviation of distance moved prior to correction) as a function of amplitude of movement and peripheral target width. Analysis performed upon this data demonstrated a significant main effect for both amplitude $F(2,8) = 11.96$, $p < .05$ and peripheral target width $F(2,8) = 5.04$. $p < .05$. Based on the findings from Experiment One it was proposed that no such differences in effective target width would be observed as a function of the manipulation of peripheral target width. Such a proposal could not be supported by the data obtained here. One reason for this failure may have been that no effort was made to observe whether or not the subjects made errors in reaching the peripheral target plate prior to

initiation of the rapid visually guided movement to the target. As a result of the failure to partition the errors, the distance moved prior to correction and following correction of the rapid aiming movement, contained error at both ends of the movement and not merely at the final target as was assumed in the analysis. This problem did not arise in Experiment One since all movements were initiated from the same point and errors were not, therefore, confounded.

Examination of the mean distance moved prior to correction showed that for 40 cm movements to the 4 cm peripheral plate the distance moved on the return rapid aiming movement was greater than for similar movements to the 1 and 2 cm plates. Furthermore, this difference was maintained following correction of the rapid aiming movement implying that for the 4 cm peripheral plate the actual amplitude of movement was greater than 40 cm. However, this did not result in the greatest effective target width. The validity of this result must, however, be suspect since much of the error obviously occured at the periphery and as such was not accounted for in the calculation of W_e around the final target (see figure 14).

In the light of these findings it is difficult to comment upon the results for other dependent variables in the experiment.

A further methodological limitation related to the timing of the movement out to the peripheral plate. Long amplitude movements were given proportionally longer times for acquiring the peripheral plate than were short movements. This difference in time may have been sufficient for subjects to perform accurate movements to the peripheral plate. Calculation of effective target widths for movements to the

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peripheral plates may have demonstrated that for all peripheral target widths the effective target width of movements to the periphery were the same. Such a finding would suggest that the most important measure of peripheral attentional demand would not be the size of the peripheral plate given by the experimenter , but rather the effective target width calculated from the length of movements to the plate provided by the subject. Effective target widths can then be calculated using a method reported by Welford (1968) and employing a correction factor reported by Crossman (1957).

Equivalence of reaction time data for the three peripheral target widths may have been due to the fact that in movements to large peripheral plates, more time was taken in the preparation of the return rapid aiming response than in acquisition of the peripheral plate. In movements to narrow plates, however, the long reaction times recorded may have been reflective of increased time required to acquire the peripheral target and not in the time required to generate an adaquate response (see figure 13(a)).

Taken together the methodological limitations of the current experiment are so numerous that an interpretation of the obtained results would be meaningless. A possible experimental paradigm which could provide information relating to attentional demand in reciprocal aiming responses without the drawbacks of the current experiment could be performed as follows. subjects would be required to move alternately between targets of differing widths. The distribution of shots around each target would be indicative of the effective target width for that target. If the proposed theory was correct then no differences in

effective target width would be obtained regardless of the size of the aimed for targets. However, differences would exist in parameters related to movement velocity.

Figure 9 shows mean and standard deviations for duration of accelerative impulse while figure 11 shows magnitude of accelerative impulse and its associated standard deviation. Both functions appear to demonstrate linear increases with amplitude for each peripheral target width. Although these results are inconclusive it is interesting to note that such results would be supportive of the Schmidt model even though the movements which produced these results were reciprocal in nature. Similar results were obtained for duration and magnitude of decelerative impulse, figures 10 and 12. The most strikingly linear relationship being for PTW 4 cm this being the peripheral target width which was predicted to show characteristics most similar to the single rapid aiming movements described by Schmidt.

General Discussion

Experiment One provided evidence which suggested that the variable application of Fitts' (1954) and Schmidt et al (1978, 1979) formulations was dependent upon the attentional demands of the tasks. Fitts law would appear to hold in conditions in which subjects were operating beyond the processing capacity of the motor system while the Schmidt relationship could conceivably hold in conditions in which subjects operated below that capacity. Experiment One indicated that the accuracy of movements could be maintained with increased velocity as long as the limited processing capacity of the motor system was not overloaded. This would suggest that when available capacity for the processing of movements is reduced, factors related to the speed of movement are affected before factors related to the accuracy of movement.

Polit and Bizzi (1979) comparing normal intact monkeys and monkeys with bilateral dorsal rhizotomy (C2 - T3) performing forearm positioning movements demonstrated that specimens performed the aiming responses with equal accuracy even when limbs were unexpectedly displaced prior to the initiation of the movement. Since visual feedback was not available to the monkeys, success in the task could not be credited to this source. Most importantly, the success of the aiming response was maintained even when the limb was displaced beyond the aimed for target and the response required changed, therefore, from a forward to a reverse motion.

Accounting for these findings Polit and Bizzi postulated that the 'motor program' specified, through the selection of a set of

length - tension parameters in the agonist and antagonist muscles, an equilibrium point which correctly positioned the limb in relation to the target. Final equilibrium was seen as a function of the passive elastic properties of the muscles in operation following a change in length or tension of the agonist or antagonist groups.

This 'mass spring' view of control has been criticised as it appears that muscle does not function according to the laws which govern the operation of normal springs. Houk (1976) demonstrated that the properties of muscles changed during movement and the critical variable in movement control was muscle stiffness, the function of length and tension. It would appear, however, that the motor system is capable by some means, of programming the end point of movements. Polit and Bizzi (1979) qualify this suggestion by proposing that the mechanism responsible for achieving final position must be paralled by a mechanism to control limb velocity, since movements acquiring the same target may differ in velocity.

The results of Experiment One may be interpreted as lending support to this modular view of movement control, since subjects in each of the three movement conditions acquired the targets with equal accuracy but with many differences in other measured parameters of movement. This may be expected if the acquisition of a target involved the execution of a program, a major component of which was responsible for the accuracy of the movement or the acquisition of the end point.

Combining this modular view of organization with a capacity view of the information processing system would suggest that as attentional demand of peripheral events increased then the capacity

available for the formulation of the response program would be reduced. Such conditions existed in Conditions One and Two of Experiment One. The observed differences in the accelerative and decelerative impulse magnitudes and durations and their associated variabilities, together with differences in movement time and velocity may perhaps be attributed to differences in attentional demands of the tasks. Increased demands on attention result in incomplete or deficcient programming of certain response parameters due to decreased availability of processing capacity.

The concept that attention is required during the initiation phase of movement has recently been forwarded by Norman and Shallice (1980). They proposed that the production of movement sequences often involved accessing a number of resources or schemas and that attentional control dictates the relevance given to a specific component schema. In terms of the first experiment it could be argued that a component schema representing the movement endpoint was given maximum activation in all three movement conditions and as a result, all three conditions resulted in equally accurate movements. The activation levels associated with other component schemas varied according to the overall attentional demand of the task. According to Norman and Shallice, in times of high attentional activity the activation levels for certain component schemas or parameters of those schemas may fall below threshold and as a result fail to be executed. At the moment of initiation of the movement the source schema representing the required act would be composed of all the parameters required to perform the act accurately and as many of the parameters for velocity as could be

fitted in the available capacity. Increased capacity therefore leads to more complete programming. The addition of further parameters occurs in an orderly fashion.

With reference to Experiment One, of particular interest is the comparison between Conditions One and Three (response to tone and self initiated). In both cases the required movement was identical and both were performed with equal accuracy. However, other measured parameters of the movements showed significant differences and it was proposed that these differences were due to the differential attentional demand at the initiation of the task. For movements requiring a planned change of direction, as in Condition Two, attention demanded was increased due to competition for processing capacity between the program controlling the movement out to the periphery and the program required to control the movement back to the target. However, the parameters resposible for accuracy of the movements are still given highest activation and the observed reduction in velocity is due to incomplete specification of velocity parameters.

It appears therefore, that attention demands of tasks critically affect the construction of response programs which resulted in the observed differences in the measured parameters of the movements.

In an earlier pilot study (Wilberg, Franks and Fishburne, note 2) results did not support a linear increase in effective target width with amplitude or movement time. Rather, subjects exhibited a bandwidth type of performance in that effective target widths could be maintained for a range of amplitudes and movement times. Incerasing the velocity of a movement did not by necessity result in an increase in effective target width. The current investigation also demonstrated this

phenomenon. Interpretation of figures 6 (a) and (b) suggest that an increase in velocity from 50 to 100 cm per second or of amplitude from 10 to 20 cm was not associated with increased W_e for any treatment condition. However, an increase in amplitude from 20 to 40 cm and velocity from 100 to 150 cm per second resulted in a uniform increase in W_e for all conditions. Whether similar plateaus would be observed at increased amplitudes and velocities cannot be deduced from the data available. The current study does support the opinion that effective target width is related to a measure of movement difficulty. The bandwidth behavior also gave rise to the possibility that the difficulty of the movement is a perceptual phenomenon in that certain movements may have been perceived to be of equal difficulty even when the amplitude and velocity were increased. There was a possibility that the maximum information contained in a movement, the actual transmitted information and the perceived information differed and that perceived information is a more sensitive measure of task difficulty. Future experimentation may be directed towards this point and the application of Signal Detection Theory may offer a means of examining the question.

Kerr (1977) reported the presence of a 51 Hz frequency movement component in the accelerometer trace of subjects performing rapid aiming movements. This component apparently became evident with practice and may have been the result of learning. This was particularly true in movements with high terminal accuracy requirements. Although the current experiments did not speak to this point, future research may demonstrate that with practice the speed of reciprocal movements increases and this increase in speed is associated with the emergence

of the 51 Hz movement component. This is a proposition which the author feels deserves further attention.

It reciprocal tasks, it has been suggested that many of the deficiencies in performance were related to the increased attentional demand of the peripheral target. Fitts (1954) demonstrated increased information transmission as a result of practice in reciprocal tasks. Such an increase may be interpreted as being the result of a decrease in attention demanded at periphery related to a decrease in the uncertainty both in the position of the peripheral target and also in the subsequently required aiming movement. It would be expected, therefore, that time spent in the transition phase of the movement would be reduced as a function of learning. This may result in reciprocal performances approaching those of single aiming responses. A further study would examine the duration of the transition phase and changes in the duration of the phase with practice and its effect on the measured parameters of movement.

The present experiments provided some evidence to support the theory that the differential application of the Fitts' and Schmidt formulations be due to differential demands on the attentional mechanisms. The locus of attention demand in reciprocal tasks appeared to be at the points of reversal in movement direction. In situations subjects operate below the capacity of the information processing system the author believes that the Schmidt formulation may hold. When subjects operate beyond the capacity of the processing system results may fit the Fitts' formulation.

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Notes

1. Crossman, E. R. W. F., and Goodeve, P.J. Feedback control of hand movements and Fitts' law. In Proceedings of the Experimental Society, Oxford, 1963.

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APPENDIX A

Fitts' Law

The concept that the accuracy of rapid movements decreased with amplitude has been known for many years. However, the close relationship between speed, amplitude and accuracy of movement received little attention from early workers in the field of motor performance. Woodworth (1899), was one of the earliest experimenters to emphasize the importance of this inter-relation. In a variety of simple motor tasks, performed with and without the aid of visual monitoring, Woodworth demonstrated that for quick, visually controlled movements, variable error increased with both amplitude and speed. Subsequently, industrial engineers advocated the use of small amplitude movements in assembly work on the grounds that the time required to complete a unit of work increases as a function of its amplitude as well as of the precision demanded by the task, (Maynard, Stegemerten and Schwab, 1948).

The application of information theory to the study of sensory, perceptual and perceptual motor functions, allowed a more specific measureemnt of man's performance capacities, (Crossman, 1955; Hick, 1952). Fitts (1954) extended the theory to embrace the human motor system. Fitts stated that the information capacity of the human motor system is specified by its ability to produce: "one class of movement from among several alternative movement classes" (p.381). Further: "The greater the number of alternative classes, the greater is the information capacity of a particular type of response." (p.381). From this, Fitts concluded that since measurable aspects of responses such as amplitude and force are continuous variables, information

capacity is limited only by the amount of variability that is characteristic of repeated attempts to produce the same response. Therefore, the information capacity of the motor system can be assessed from measures of variability of responses which are meant to be uniform.

Fitts' (1954) theory stated that, since the information transmission capacity of the motor system is fixed, it could be expected that if repetitive movements of average amplitude are 'speeded up' then each movement can provide less information and, therefore, movement variability will increase by a specified amount. Similarly, if the amplitude is increased then variability in the movement, and/or its duration, will also increase. Stating the specific hypothesis:

> "If the amplitude and tolerance limits of a task are controlled by E, and S is instructed to work at his maximum rate, then the average time per response will be directly proportional to the mimimum average amount of information per response demanded by the particular conditions of amplitude and tolerance." (p.383)

Fitts tested the hypothesis using a number of tasks, including: a reciprocal tapping task; a disc transfer task and a pin transfer task. In all cases Fitts found that: "The rate of performance of all the tasks studied increased uniformly as movement amplitude was decreased and as tolerance limits were extended." (p.387).

In order to test the results against a prediction that the information output of the motor system in any task is relatively

constant over a range of amplitudes and accuracy requirements, Fitts formulated an index of difficulty which specified the minimum information required for organizing each movement. Minimum organization is the specifying of one from several possible amplitudes within which the movement is to terminate. In binary notation:-

$$ID = -\log_2 \frac{W}{2A} \quad \text{bits/response.} \qquad (1)$$

Where ID = Index of Difficulty

W = Tolerance range in inches

A = Average amplitude

The results of Fitts experiments confirmed that the movement time varied with task difficulty in such a way that ID was constant over a wide range of amplitudes and tolerances. That is to say, that movements of different amplitudes but of equal difficulty in terms of information, are of approximately equal duration. The average time per movement, MT, was related to A and W by the following relation:-

$$MT = a + b \log_2 \frac{2A}{W} \qquad (2)$$

where a and b are empirically fitted regression parameters.

According to the information theory interpretation, the slope parameter, b, is the inverse of the motor system processing rate channel capacity. In the previous studies of arm movements

b has been in the region of .100 bits/second. Fitts (1954) speculated that different limbs may show different information processing rates. Hancock, Langolf and Clark (1973) supported this showing an information processing rate of 20 bits/second for very small amplitude movements of the fingers and wrist. It was also shown that the times for a variety of microminiature assembly tasks, performed under microscopes, were proportional to the index of difficulty, ID. In general, Fitts' Law has been shown to hold in a variety of experimental situations and across a broad perspective of populations (Kerr, 1973; Welford, Norris & Shock, 1969).

Since the introduction of Fitts' Law there have been many attempts to modify the relationship to obtain more accurate descriptions of obtained data, but little or no improvement has resulted from this work. Welford (1960), using data from Fitts' (1954) reciprocal tapping task, formulated an equation which best fitted the data to a straight line:-

$$MT = K \log (A/W + .5) \qquad (3)$$

According to Welford: "This formulation makes movement time dependent upon a kind of Weber fraction in that the subject is called upon to distinguish between the distances to the far and near edges of the target." (p.147). Welford also identified situations in which the subject did not use the full target width. Under these circumstances the subject is transmitting more information than that calculated by equation three since the effective target width is

narrower than the target. The narrowing of the target width, W, is reflected in a reduction in errors and, according to Welford, if this is allowed for then equation (3) holds reasonably well.

Crossman (1957) described a method for correcting for errors based on the fact that the information in a normal distribution is given by: $\log_2$ (2E), where is the standard deviation of the distribution. Since (2E) = 4.133 and plus or minus one half of this includes approximately 96% of the distribution, Crossman argues that if approximately 4% of shots fall outside the target that $\log_2 W$ is an accurate representation of the information contained in the distribution of shots. Also, if errors exceed 4% then the 'effective target width', W_e, is greater than W and, if errors are less than 4% W_e is less than W. Welford (1968) showed that Fitts' data, as plotted using equation (3) and corrected for errors using the Crossman method closely approximated a straight line passing through the origin.

Numerous experiments have produced results which are in striking agreement with Fitts. Knight and Dagnall (1967), using a task in which subjects had to align a pointer alternately between two targets, obtained results which closely fitted equation (3). Fitts and Peterson (1964) obtained results closely fitting equation (3) for 'single movements' carried out after a separate signal to move. Fitts and Radford (1966) demonstrated that accuracy improved as time taken to complete the movement increased, however, it was not affected by time taken to prepare, and the rate of gain of information was little affected whether the instructions were for

speed or accuracy.

Theories Accounting for Fitts' Law

The most widely accepted explanation for the phenomenon described by Fitts was that presented by Crossman and Goodeve (1963), and later represented by Keele (1968). The theory is based on two assumptions: (a) that the subject is able to detect errors in movement and subsequently issue corrections; and (b) that the initial movement and subsequent corrections have a fixed relative accuracy. Crossman and Goodeve demonstrated that movements were not smooth but showed evidence of acceleration and deceleration with fixed periodicity, suggesting that movements consisted of a series of impulses, taking approximately the same time, but differing in velocity. The first movement may, for example, cover half the distance to be covered, the second the next quarter, and the next the next eighth, and so on. This explanation emphasizes feedback control in rapid movements with limitation in movement speed being defined by the number of corrections the subject must make to acquire the target. Using this argument, Keele (1968) has shown that Fitts' Law can be derived mathematically.

Findings from research examining movement patterns are equivocal, showing that movement corrections may (Annett, Golby & Kay, 1958; Brown & Slater-Hammel, 1949) or may not (Langolf, Chaffin & Foulke. 1976) take place in aiming responses.

The Crossman - Goodeve theory has, however, come in for much

criticism on a number of counts. Logically it can be seen that correcting for errors in response selection would take at least one reaction time to perform since a new temporal-spatial pattern of movement needs to be intitated. This would take between 120 and 200 msecs. Schmidt, Zelaznick, Hawkins, Frank and Quinn (1979), suggest that such corrections may, in fact, take longer than one reaction time.

The Crossman-Goodeve theory assumes a correction every 200 msecs. with the first coming 200 msecs. after the initiation of the movement. Schmidt et al. (1979) suggest that if the first correction appears 200 msecs. after initiation of the movement, and the reaction time for the correction is 200 msecs., then the error must have been detected prior to or at the moment movement was initiated.

> "Logically it would seem that some initial portion of the movement must be carried out before the system could detect that the movement was in error." (Schmidt et al., 1979, p.5.)

By this arguement it would appear that the first correction could not occur 200 msecs. after the error was detected and the actual time of correction would, perhaps, be nearer 300 msecs. after the movement was initiated.

Furthermore, the Crossman-Goodeve (1963) model holds that corrections are required in a movement. Langolf (1973) has noted, however, that microscopic movements show little evidence of corrections, perhaps because they are programmed correctly from the start. Schmidt et al. (1979), regard the neccesity for corrections in

a movement, and the failure to account for movements requiring no corrections, as a conceptual weakness of the model.

Another interesting objection arises from the work of Hick (1952) examining choice reaction time tasks. The suggested time for a single correction of 200 msecs. assumes a simple reaction time where the number of possible errors which can occur in the movement is reduced to one. This is obviously not the case, as the number of possible errors greatly exceeds one and the situation is, therefore, one of choice reaction time. Therefore the suggested time for correction of 200 msec would seem to underestimate the time required for a correction.

The Psychological Refractory Period.

The psychological refractory period (PRP), the delay in responding to a stimulus while another is being processed, was first reported by Welford (1952). In accounting for the phenomenon Welford proposed that:

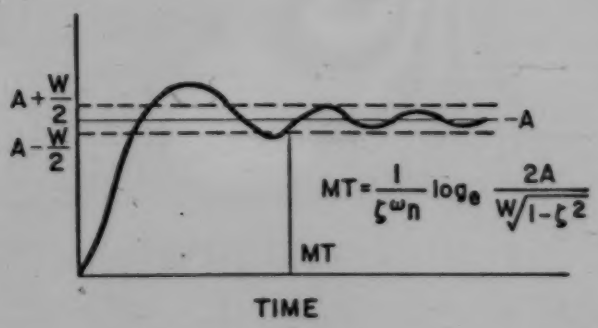
1. All input and output streams are controlled by a common processor, and
2. The processor acts sequentially on current inputs, rather than simultaneously.

With regard to the Crossman-Goodeve theory, it would appear unlikely, in the light of PRP, that responses to two closely following feedback stimuli could occur within the suggested 200 msecs., since processing of the second stimulus could not occur until a response to

the first had been made. Even assuming the parallel processing model of McCleod (1977), which would allow processing of the second feedback stimulus along with the first, a decrement in response to the first stimulus would be noted. In neither case could processing and response be completed within 200 msec.

Systems Models

Langolf et al (1976) present the Crossman-Goodeve theory as representing a first order system response. A second order underdamped system is also shown to settle according to Fitts' law, (see figure below), and it was proposed that further linear control systems models have outputs obeying Fitts' law.



Representation of second order underdamped system from Langolf et al (1976, p. 115).

An examination of a wide range of amplitudes using the Fitts' reciprocal tapping task was made in order to confirm the applicability of control systems models to Fitts' law. Under large amplitudes it was found that:-

> "...linear control models are untenable explanations of Fitts' law. The human trajectories are obviously non-linear. For all linear models discussed, decreasing the terminal tolerance W simply has the effect of adding more settling time to the same basic movement trajectory. However.... changing the tolerance has the effect of completely altering the human's movement trajectory. In particular the Crossman-Goodeve and Keele constant time, constant accuracy discrete corrections models specified that the movement shouldon the average achieve a given deviation from target center (P A) after each discrete correction n at time nt. Thus the discrete corrections model must generally show the same rate of progress toward target center regardless of terminal tolerance W. Therefore, if a discrete correction mechanism is present (but masked by inertia), then in order to produce the varied trajectories of figure 12, the time per correction (t) and/or relative accuracy (P) must change as a function of tolerance demands (W). The real explanation of Fitts' law in terms of method of human control must be more complex and non-linear."

Langolf et al. (1976) found that larger amplitude movements did not show evidence of break points indicating a discrete correction process. Decreasing the tolerance, W, merely had the effect of progressively decreasing the velocity of the movement in approaching the target.

Based on experimental evidence that the hand slows down as it approaches a target (Peters & Wenborne, 1936; Taylor, 1947; Edwards, 1965) Howarth, Beggs and Bawden (1971) proposed an intermittent feedback theory for the control of aiming movements. Howarth and Beggs (1970) proposed the existance of a visually mediated intermittent correction mechanism since removal of visual

feedback when the hand is close to the target has little effect on terminal accuracy. This was only the case if there was less than one corrective reaction time between removal of feedback and the hand reaching the target. The theory proposed that the error on target was related to the velocity of the hand during the terminal phases of the movements being made at different speeds. Howarth et al. (1971) provide evidence to support this theory for slow movements. Beggs and Howarth (1972) provide further evidence to support the theory that the error on target is proportional to the distance away at which the last correction was applied.

This theory, however, falls prey to the same criticism as the Crossman-Goodeve theory of movement control in that it can not account for movements which are completed within one corrective reaction time.

Alternative Theories

Motor Output Variability

The previously reviewed theory was based on the subject's ability to process feedback information and to make corrections based on this information. Schmidt, Zelaznick and Frank (1978) suggest that researchers have consistently disregarded the possibility that the output of the human muscular system is contaminated by "noise" (within subject variability) and that this variability is related to the parameters of the movement, i.e., amplitude and speed. According to Schmidt et al. (1978) central to both theories is the notion of the motor program, which can be described as a set of prestructured motor

commands, which, when executed, will complete a movement without involving peripheral feedback. Schmidt et al (1979), proposing the theory of motor output variability, suggested that if movements can be structured in advance, then errors contained in the program, or in the recruitment of motor units involved in its execution, cannot be corrected until the program has been completed.

Evidence is cited by Schmidt et al (1979), from the areas of neurosciences (Brooks, 1974) and motor behaviour (Pew, 1974; Schmidt, 1975, 1976) to support the notion that movement control, especially in rapid movements, is carried out via the motor program. Shapiro (1977) even suggests that motor programs may control movements of duration as long as 1300 msecs.

The basic premise of the theory of output variability is that the variability in horizontal distance travelled (effective target width, W_e) in an aiming movement is proportional to the within subject variability of the velocity after the end of acceleration. Since the velocity of a movement is proportional to the magnitude of the accelerative impulse, the variability in velocity is, consequently, proportional to variability in impulse force and the variability in time over which the impulse is acting. As a result the theory proposes that the effective target width, W_e, is proportional to the variability in impulse force and impulse duration.

Schmidt et al. (1979) derived the following proportionalities:-

1. Effective target width and amplitude are proportional.
2. Impulse variability and movement time are inversely proportional such that σ Impulse $1/MT^2$

3. Citing Michon (1967) who demonstrated that the longer an interval of time to be metered, the larger the variability in metering, Schmidt et al proposed a relationship between impulse duration and movement time. Further, assuming a constant force amplitude, that σ Impulse $\propto$ MT.

4. Combining (2) and (3) Schmidt et al. propose that:

Impulse $\propto 1/MT$

5. Combining (4) and (1) gives the basic statement of the model:- $W_e \propto 1/MT$

> "The clear implication of this model is that as one asks the subject to move farther or faster, the subject does so with greater noise in his force- and time-production mechanisms, resulting in greater error in reaching the aimed for target." (Schmidt et al., 1979, p.194)

Schmidt et al propose that this notion of speed accuracy trade-off fits well with Fitts' equation, since it suggests that as the subject attempts to move faster he/she will make more errors.

> "Thus the present theory sees the limitation in the subject's movement time as an indirect result of his inability to be accurate because of variability in the force production and time-production mechanisms; this is quite different from the Crossman-Goodeve (note 1) model, which suggests that the limitation in movement time is the number of corrections the subject must make in arriving at the end point." (p. 195)

This is the Impulse Timing view of motor control.

Feedback in Motor Programming

Before presenting experimental evidence accumulated by Schmidt et al to support the motor output variability theory; it is intended to review the feedback versus motor programming controversy.

Klapp (1975) suggests that, in a choice reaction time experiment, the signal to respond informs the subject which of a set of possible responses is to be made. During the reaction time interval several processes may occur, of which interpretation of the signal, and programming or preparation of a response are two. Henry et al., (1960) and Klapp (1974), have suggested that when the number of alternative responses is kept constant, then increases in reaction time as a function of response parameters may be interpreted as reflecting changes in the time required to generate the response program.

Klapp (1975), argues that, in the Fitts' and Peterson (1964) paradigm, if reaction time reflects response programming, then choice reaction time should increase as the precision required is increased by reducing the size of the target. However, Ells (1973) demonstrated that this was not the case. Klapp (1975) goes on to say:

> "Although movement time, measured from the moment the stylus leaves the rest position until target contact occurs, depended on both target size and movement length, reaction time was independent of these parameters. This negative result may mean that the response is under feedback control rather than programmed in advance." (p. 147)

It was stated earlier that research findings concerning the question of corrections were equivocal. Klapp (1975) proposes that in long, accurately terminated movements, the whole movement may not be programmed in advance, accounting for the independence between reaction time and parameters of the movement. Short movements, which may not display corrections (Langolf et al, 1976), could be programmed in advance. If this were the case then more complex responses would require longer programming, leading to the observation of increased reaction time as required precision for short movements increases.

In a single aiming movement, Klapp (1975) demonstrated that the relationship between amplitude and the $\log_2$ of target width appeared to be linear for long movements but not for short movements. This, for short movements, represented a departure from Fitts' Law. This departure, according to Klapp (1975) suggests that: "....short movements are programmed ahead of time and executed ballistically. On the other hand, Fitts Law should and does hold for long movements which are under feedback control according to the present analysis." (p. 150). This analysis would seem to parallel that suggested by Schmidt et al (1978, 1979) in the theory of motor output variability. Further, Klapp (1975), demonstrated a linear relationship between reaction time and target width for short movements, such that reaction time increased as target width decreased indicating a longer processing time for more precise movements.

Klapp (1975) contended that long movements were under feedback control while short movements were programmed in advance. In a second experiment, in which visual feedback was disrupted by turning out

illumination, it was found that long movements were totally disrupted, while for short movements reasonable accuracy was maintained.

Schmidt and McGown (1980) regard the controversy concerning the locus of movement control as one of the most persistent in the field of motor behaviour. Peripheralists posit that movement is controlled by some combination of feedback from the responding limbs, the visual and auditory systems and the vestibular systems. This position takes two basic forms:

1. A stimulus response chaining hypothesis, James (1980), which suggests that successive responses are elicited by successive cues in the environment. Entire skills can be executed in response to a starting stimulus, in the absence of other external stimuli, since each succeeding response is elicited by the pattern of internal stimuli from the preceding response (Greenwald, 1970).
2. Adams' (1971) closed-loop hypothesis which proposes that feedback is compared to some stored referent which represents correct performance. Errors are determined as deviations from the referent and corrections are issued on this basis.

Centralist theory, conversely, as developed by Henry (1960) and Fitts (1964), emphasizes a central process that is not dependent upon sensory monitoring. Keele (1968) states that a motor program can be viewed as:

> "...a set of muscle commands that are structured before a movement sequence begins and that allows the entire sequence to be carried out uninfluenced by peripheral feedback." (p. 387)

The central control hypothesis proposes, therefore, that skilled movements are organized and initiated by some central control process. Knowledge of movement does not depend on the monitoring of afferent input.

One argument against stimulus-response chaining theory involves the rate of processing of feedback information. Lashley (1951) suggested that this processing was too slow to account for rapid sequences of movements such as finger movements in piano playing. Keele (1968) and Glencross (1975) report the time taken to react to kinesthetic information is in excess of 100 msecs , while Keele and Posner (1968) increase this time to between 190 and 260 msecs for visual feedback information. Furthermore, in the complex skill situation, which usually involves perceptual and response uncertainty, Glencross (1977) suggests the shortest interval of intermittent functioning is at least 300 msecs.

Pew (1966), in a task which involved the repositioning of a constantly moving visual target by alternately pressing response keys, demonstrated a change in strategy from feedback dependent pattern early in practice to control by motor program. Early responses were made only after delays in which feedback information about the effectiveness of response was assessed. Later in practice, however, subjects responded rapidly, indicating less dependency on continuous monitoring of sensory feedback and instead, the control of response sequences rather than single units.

Speech, a complex, serially organized skill, shows evidence of central control. Lenneberg (1967) states:

> "Thus we gather that the rate at which individual muscular events occur (throughout the speech apparatus) is of an order of magnitude several hundred events every second. It is evident that the activation of so many muscles in such a short time span cannot depend upon volition alone. There must be some automations - whole trains of events that are programmed and run off automatically." (p. 92).

Support of this theory and evidence of 'tone units' in speech is given by Boomer (1965) and Laver (1970).

The most persuasive evidence in favour of central processing comes from the studies of deafferentation in which kinesthetic feedback is prevented in animals by surgically cutting dorsal roots which supply afferent feedback to the central nervous system. Keele and Summers (1975) suggest that if skill can proceed without kinesthesis then stimulus-response chaining, which depends on kinesthetic feedback, cannot explain the sequencing of the skill.

The most impressive experiments of this nature involved the the elimination of sensory feedback in the rhesus monkey. Taub and Berman (1968) repeated the experiments of Mott and Sherrington (1895) by surgically severing the dorsal roots supplying afferent input from one of a monkey's front legs. This procedure, therefore, eliminated sensory feedback without affecting efferent input to the muscles. Mott and Sherrington (1895) observed that the monkey failed to use the deafferented limb, which lent support to the stimulus-response chaining theory of movement control. However, Taub and Berman (1968), after restraining the normal limb, demonstrated that the monkey could, in fact, use the deafferented limb.

Furthermore, when both limbs were deafferented:

> :...the animals were able to use the limbs rhythmically and in excellent coordination with the hind limbs during slow and even moderately fast ambulation." (p. 177)

Taub and Berman (1973) have further shown that monkeys deafferented and visually blocked soon after birth learn to walk, suggesting that sequencing of movements in walking is not dependent on normal feedback.

Criticism of the Taub and Berman technique centers around the question of total elimination of sensory feedback. Taub and Berman showed that no cortical responses occured when nerve ends in a deafferented limb were stimulated. However, Bossom (1974), suggested that some afferent fibers may enter the spinal cord through the ventral root and, therefore, escape severing in dorsal root cutting. Some reservation must, therefore, exist with regard to these results.

More significantly, perhaps, is the emphasis Taub and Berman placed on the ability of the deafferented monkeys to perform gross movements. Bossom (1974) reported that these movements were produced without elegance, suggesting that gross movements can be performed in the absence of sensory feedback but fine motor skills such as manipulative skills, can not.

Ischemic nerve block techniques have been employed in studies of human movement in an attempt to block afferent sensory information. Of importance in this technique is the differential effect on

sensory and motor systems. Loss of sensory information occurs much sooner than loss of muscular power (Magladery, McDougal & Stoll, 1950). Laszlo (1966, 1967, 1968) in a number of studies has shown gross impairment of performance as a result of ischemic blockage. However, Glencross and Oldfield (1975) raise objections to the ischemic nerve block technique by demonstrating gross motor impairment due to the cuff and also the presence of some sensory information arising distal to the cuff. Glencross (1977) states that:

> "Consequently, the motor deficit observed following ischemic nerve block is not solely the result of blocked kinesthetic sensation, and thus its relevance to the issue of central versus peripheral control of movement cannot be directly assessed." (p. 21)

Evidence has been presented, therefore, which would suggest some combined or integrated use of central and feedback processes in the organization and performance of movements.

Philips, Powell and Wiesendanger (1971) demonstrated that positional information from the eyes arises from the receptors in the extraocular muscles. Skavenski (1975) demonstrated that feedback control is important in control of eye movement, concluding that: " these inflow signals are accessible to the occulomotor system for the control of eye position." (p. 225). Also, Provins (1957) demonstrated that blocking sensory information by anaesthetizing the metacarpal-phalangeal joint, resulted in impairment in reproducing pressure by flexion.

Further support for the theory comes from the study of effects

of delayed and augmented feedback. Smith (1962) in a review, presents evidence of jerky, uncoordinated movements as the result of delayed visual feedback. Glencross (1975) reports that augmented feedback, when closely related to the task, enhances performance.

This treatment has seen feedback control and motor programming as mutually exclusive modes of control. However, each theory is seen to be deficient to some extent and the possibility that some integrated control mechanism must exist as the means of coordinating skilled movement. Glencross (1975) suggests: "...that for a central control process (e.g. a motor program) to be fully effective, it must be integrated with peripheral sensory information at some stage." (p. 25).

This possibility will be discussed later in the chapter.

Evidence For The Theory Of Motor Output Variability

Schmidt et al.(1978, 1979) conducted a number of experiments in an attempt to confirm the relationships stated earlier in this chapter. Since these are the basis of the theory of motor output variability, a review of these experiments is felt to be in order.

The most important relationships proposed were that variability in force produced was proportional to the force produced, and that the within subject variability in impulse duration is proportional to the impulse duration. These variabilities in force and time could be introduced into the system in two distinct ways.

Either, they could be caused by the subject changing the goal of the response from trial to trial, variability thereby being due to changes in what was programmed. Or, the subject may repeat the same program over and over and variability is introduced as noise downstream from the program, causing different outputs for different trials. In testing the proposed proportionalities, Schmidt et al. (1978, 1979) attempted to have the subject repeat the same movement every trial, thus eliminating the possibility of variability due to choosing different responses.

Variability in Force

Using a fixed lever and attached strain gauge subjects exerted force in order to shoot a dot across an oscilloscope screen to a target. This was done in time with a metronome set at one response per 800 msecs. Force required was varied and a strong linear relationship between the within subject variability in force and the amount of force produced was observed over a wide range of forces. Also, a strong linear relationship between impulse duration and movement time was apparent and this relationship appeared to be a proportional one.

Amplitude

If the amplitude of a movement were doubled, however, the movement time remains constant, Schmidt et al argue that the velocity at the end of acceleration must be twice as large. Impulse for acceleration can only be doubled by increasing force, and variability

of force is proportional to the amount of force produced. Since variability in the impulse is proportional to the effective target width then it follows that:

$$W_e \propto \text{Amplitude}$$

Movement Time

Assuming no variability in the duration of an impulse, halving the movement time for a fixed amplitude movement requires the impulse to increase four fold. Extrapolating from this it can be seen that variability in the impulse will be inversely proportional to the square of the movement time (MT):

$$\text{Impulse} \propto 1/MT^2$$

Since, however, variability in length of impulse is proportional to impulse duration and therefore movement time, then the variability in the impulse is proportional to the movement time:

$$\text{Impulse} \propto MT$$

Combining these effects it can be seen that the impulse variability is proportional to 1/MT and hence:

$$W_e \propto 1/MT$$

Amplitude and Movement Time

Since W_e is directly proportional to amplitude and inversely proportional to movement time, then:

$$W_e \propto A/MT$$

This is the basic statement of the Schmidt et al (1978, 1979) model, which relates the three variables of movement time, amplitude and movement accuracy in a single expression.

The Single Aiming Paradigm

Schmidt et al (1979) conducted a number of experiments using a single aiming paradigm. The technique involved manipulating amplitude and the movement time allowed and measuring the resultant effective target width. For long movement times (up to 500 msecs) the relationship: $W_e \propto A/MT$ did not hold, however Schmidt et al cite Keele and Posner (1968) who found that visually based corrections are possible with aiming responses as short as 260 msecs. For short duration movements (less than 200 msecs), however, a strong linear relationship between A and MT was found, lending strong support to the model. However, the relationship was not proportional, a finding partly attributed to error in measurement and also noise in the motor system not related to the task being performed.

The Locus of Variability

Schmidt et al (1979) approach the question of variability by assessing the variability added during the various processes contributing to movement. For example, variability may be added as a result of selecting an inappropriate program. However, in a single aiming movement this variability is small since there is little uncertainty about what to do in aiming at the target. Another source of variability is seen as noise, which is added downstream from

parameter selection. Burke and Edgerton (1975) suggest, in physiological terms, that noise might exist in terms of how the neuronal information to the motor neuron pool in the spinal cord becomes translated into the activation of a certain number of motor units, which ultimately determines the amount of force produced.

Based on the findings of Kelso, Southard and Goodman (1979a, 1979b), which demonstrated that simultaneous left and right hand aiming responses had similar kinematic properties, Schmidt et al (1979) examined a two handed paradigm in an attempt to isolate the invariant features of the motor program. For example Kelso et al (1979a, 1979b) found that subjects could move the hands simultaneously different heights or distances, suggesting that these features were not invariant. However, they could not move the hands with different movement times, suggesting that this was common to the two hands, and an invariant feature of the movment determined by the motor program. Logically, Schmidt et al (1979) argue that:

> "Whatever these common paramameters might be, variability in their selection will be evident in the behaviour of both hands."

Using a two handed aiming task Schmidt (1979) reports that for movement time 69% of the variability in movement times was due to program or common parameter selection and only 31% associated with subsequent factors, (based on between hands correlations). For spatial measures of accuracy, however, only 1% of the variability could be associated with program selection. Schmidt concludes that:

> "Very little of the variability in the spatial aspects of a single aiming response is associated with variability in program selection; rather; the variability appears to be caused by variability in the particular parameter selection or in motor unit recruitment. Locating the exact source of this latter variability could have important implications in understanding motor behaviour." (p.433)

Schmidt et al (1979) extend the theory of impulse variability and programmed motor control to apply to motor responses other than hitting a target. In a rapid timing rask Schmidt reports that the variable error for timing is essentially unrelated to the amplitude of the movement and directly related to the movement duration, (except for very small movement velocities). These results are also supported by Newell et al (1979).

In the reciprocal tapping task Schmidt reports correlations ranging from .67 to .84 for individual subjects between effective target width and impulse force.

> "This result provided some support for the idea that the impulse variability is a major determiner of W_e in the reciprocal-movement task." (p.440)

Schmidt et al (1979) go on to report that:

> "We have shown that the variability in movement endpoints (W_e) is linearly and directly related to the movement amplitude, independent of the movement time and independent of the mass to be moved." (p.446)

However, with movement times in excess of 200 msecs. Schmidt et al

suggest that their model does not account very well for the effects of amplitude and movement time, which are accommodated well by Fitts' Law. Subsequently it is suggested that Fitts' Law, which is deriveable from the principles of feedback (Crossman and Goodeve, 1963; Keele, 1968) might account for slower responses while the Schmidt et al (1979) theory of motor output variability is more effective for movements of less than 200 msecs. However, Schmidt contends that the Fitts' Law may hold when the subject is attending to the movement. With movements not requiring the subjects attention it is possible that Schmidt's theory may hold even for slower moves.

> "We prefer to argue that when subjects make a programmed movement in everyday settings, they do in fact determine the distance and movement time in advance, with the movement accuracy being the result of these choices." (p.448)

Schmidt et al (1980) propose that the human operator is able to switch between controlled modes of action and actions based on motor programming on the basis of available processing capacity, and the attention demands of a particular situation. Schmidt suggests that subjects adopt feedback control when no other actions are present or the actions require little attention, since the 'cost' of allocating attention is no problem. However, when attentional demands are high, Schmidt suggests subjects abandon the costly feedback-based mode of control in favour of a pre-programmed mode.

The evidence presented by Schmidt et al (1978, 1979) could be interpreted as supporting a model of behaviour in which, for rapid

movements, the subject executes motor programs and variability around the target is due to 'noise' in the motor system. For longer duration movements feedback control is adopted, and noise in the system can, therefore, be corrected for, resulting in less variability around the target. Schmidt's model, therefore, proposes a trade-off between accuracy and attentional demand of a task.

This theory is logically appealing but it does not account for one area of experimental evidence. When ballistic aiming movements are performed, i.e. less than 200 msecs. in duration, there is insufficient time for feedback loops to operate for ongoing control purposes. The movements, however are still performed smoothly, and with precision (Glencross, 1973, 1974). When feedback is blocked or distorted, the fine grading of movement and its temporal precision are lost, e.g. Bossom (1974). It would appear, therefore, that in order for a central control process (a motor program) to be executed efficiently it must be integrated in some way with peripheral sensory information. Schmidt et al (1980) propose a switching mechanism based on attentional demand, which does not call for the completely integrated system that is apparently in operation.

To this end Glencross (1977) proposed a two stage integrated model. The first stage, or executive control system, is feedback dependent and is based on an analysis of th input and the relation of the signal to the response. The second stage consists of a motor program which once initiated will run its full course without intervention.

This theory can also account for attentional demand, since

the executive system can combine predictable sequences of action and form larger units of action. In ballistic movements it is proposed that the single channel mechanism can operate directly through the motor program, that is to say, no time is spent in routine analysis by the executive system.

This proposition is well stated by Adams (1976):

> "This is a compromise hypothesis which seems very difficult to test. It is insufficient to show that either the motor program or feedback are governing agents for movement (the issue which is at the center of our scientific eye at the moment). Rather it must be shown that both the motor program and feedback are operating and also, the circumstances of their interaction must be demonstrated." (p. 99)

Other Theories of The Locus of Variability

Evidence From Neurophysiology

Bizzi, Polit and Morasso (1976) conducted research aimed at understanding some of the mechanisms whereby the central nervous system terminates a given phase in a motor sequence and maintains a newly acquired position. Using normal, intact monkeys and deafferented monkeys, Bizzi et al. (1976) investigated the extent to which the termination of a centrally initiated head movement (coordinated eye-head response to the unexpected appearance of a stimulus in the animal's visual field), and the subsequent maintenance of posture, depended on the proprioceptive afferent input generated during the movement itself or, instead, the central programming of the movement.

Using vestibulectomized but otherwise intact monkeys, load

disturbances were applied unexpectedly at the beginning and throughout centrally initiated head movements. The aim was to provoke a proprioceptive response in all types of neck receptors and to observe the outcome of this stimulation on the final head position. In a second set of experiments the afferent input was interrupted by cutting servical and thoracic dorsal roots and observing how the absence of proprioceptive feedback affected final head position.

Results indicated that final head position was determined by a central pattern of neural impulses which was programmed and was not reset by afferent proprioceptive impulses generated during the movement. Furthermore, Bizzi et al. (1976) provided evidence to support the theory that final position is an equilibrium point dependent on the firing rate and recruitment of motor neurons, the length tension properties of the muscles involved and the passive elastic properties of external loads.

This work cast doubt on the role of proprioceptive feedback in the control of movement endpoints and also re-emphasized the role of length tesion properties of the opposing muscle groups in determining the position of the limb in which torques in the two directions about the joint are equal. This idea was first posited by Crossman and Goodeve (1963) and termed the "mass-spring" view of motor control. It was later studied independently by Asatryan and Fel'dman (1965) and Fel'dman (1966a, 1966b).

Further work by Bizzi et al. (1978) has demonstrated that corrective responses to unexpected loading of muscles during a movement are only in small part due to reflexive activity. It would appear

that the majority of corrective action is due to the mechanical properties of the muscle itself.

> "..showed that during the first 200msecs., the contribution of the neural component relative to the applied disturbance ranged from 10 to 30% of full compensation in deafferented animals and that a significant proportion (from 20 to 40%) of the total compensation was due to the intrinsic mechanical properties of the musculature." (Bizzi et al. 1978 p. 553)

Possibly the most important work conducted by Bizzi and Polit (1979) examined the processes controling arm movements. Bizzi et al. examined normal, intact monkeys and monkeys with bilateral dorsal rhizotomy, (C2 - T3) performing forearm positioning tasks. In both cases the pointing tasks were performed without sight of the arm. During the experiments the arms were unexpectedly displaced prior to initiation of the movements. The intact monkeys were able to move accurately to the target. Similarly, this procedure yielded qualitatively the same results in deafferented monkeys. Bizzi et al (1979) suggest that these results can be explained by postulating that the motor program specifies, through the selection of a set of length tension properties in agonist and antagonist muscles, an equilibrium point between these two sets of muscles that correctly positions the arm in relation to the visual target.

The position is qualified by the suggestion that this process must be accompanied by a mechanism controlling arm velocity. Also, the mechanism by which the described process is intitated is still unknown. Bizzi et al (1979) state that:

> "The postulated independence of the processes controlling velocity, indicates that a number of parallel processes underlie arm movement, and that motor control may be thought to be organised in a modular fashion." (p.193)

Results also demonstrated that displacing the arm from the body caused the responses of deafferented monkeys to become inaccurate, while the intact monkeys quickly compensated for the new relative position of the arm to the body. According to Bizzi et al:

> "The dramatic inability of the deafferented monkey to execute accurate pointing responses in an unusual postural setting or when a constant bias load was applied underscores the great importance of afferent feedback in updating and adjusting the execution of learned motor patterns when posture is changed." (p.193)

This evidence presented is, as Schmidt (1980) comments: "particularly damaging for an impulse timing view of motor programming, at least for this kind of movement." (p.151)

Evidence which tentatively supports the proposition of parallel processes in the control of movement is given by Falkenberg and Newell (1980). They report that reaction time, (the time between a start signal and the beginning of a movement) has been generally accepted as a measure of the processing demands of movement initiation. Kerr (1978) and Klapp (1976, 1978) suggested that variations in reaction time due to manipulation of various response parameters indicated the degree to which the parameter was a feature in response programming.

The only response parameter consistently seen to affect reaction

time, as reported earlier, has been movement time (Kerr, 1978; Klapp et al, 1974). However, Falkenberg and Newell (1980) suggest that initiation time differences attributed to movement time could equally have been explained by variations in average velocity. They cite the work of Klapp and Erwin (1976) in which, as average velocity of movement increased, initiation time decreased in a systematic fashion. Newell et al (1979) demonstrated further, that different movement time amplitude combinations, which generate the same mean velocities, had similar initiation times. Falkenberg and Newell state that:

> "It seems, therefore, that average velocity rather than movement time may be the key kinematic parameter determining response initiation time." (p.761)

Falkenberg and Newell (1980) demonstrated, using self-timed movements, simple response techniques, and choice response techniques, that initiation time decreased as average velocity of movement increased.

Conclusions from this research should be treated with caution however, since, as demonstrated by Schmidt et al (1978), initiation time covaried with velocity and also impulse force. According to Falkenberg and Newell (1980):

> "Indeed it seems entirely reasonable that the system is programmed around the force-time or impulse requirements of the response, which are dictated by the mass of the system being moved, together with the kinematic demands particularly average velocity, of the criterion response. In other words, kinematic requirements may be mere concomitants or determiners of programming rather than features of the program." (p.767)

Although the theory that control and coordination of movement may be partly based on the viscous and elastic properties of the muscle joint system, has only recently been recognized, it was proposed as early as 1947 by Bernstein (reported in Bernstein, 1967). Bernstein suggested that when muscles acting at a joint are constrained to act as a unit, the linkage is describeable as a class of vibrating system whose physical and behavioural characteristics are qualitatively similar to a mass-spring. Asatryan and Feldman (1965) and Feldman (1966) demonstrated that when subjects were required to hold a constant angle at the elbow joint against a resistance, changes in the load resulted in changes in joint angle that were predictable as the behaviour of a non-linear spring.

Kelso and Holt (1980) suggest that this mass-spring account of limb localization reduces many of the problems confronting theorists in movement control.

> "Perhaps its major characteristic for our purpose is that it is intrinsically self equilibrating: once set in motion the spring will always come to the same resting length for any particular load value. Neither an increase in the initial deflection of the spring from its resting length nor temporary perturbations will prevent the achievement of the equilibrium point...." (p.409)

One concern of theorists has been to explain how the brain accommodates variability in the context within which movements occur; labelled by Turvey et al (1978) as "context-conditional variability." Simply, this refers to the lack of an invariant relationship between centrally generated signals and movement autocues, what Schmidt (1978,

1979) would call motor-output variability. Since the mass-spring disregards initial conditions and is impervious to perturbations of movement trajectory, it goes some way to alleviating this problem.

Aslo of concern is how end point might be achieved through a variety of movement trajectories and diverse kinematic details such as velocity and amplitude. According to Kelso and Holt (1980) it is not the kinematic details but the underlying dynamic parameters of mass, stiffness and viscosity that are important in the regulation of movement. Specification of these dynamic parameters determines kinematic details and variability in these parameters will effect the equilibrium process only in terms of the observed kinematics but not in achievement of equilibrium position.

Kelso and Holt (1980) have attempted to determine whether any of the observed kinematic characteristics that occur in localization violate the mass-spring model. One prediction is that production of terminal location will be superior to production of amplitude since terminal location is specified by a motor program as an equilibrium point. However, amplitude production requires programming of new equilibrium points as the initial conditions vary. Kelso and Holt (1980) demonstrated that reproduction of location is hardly affected by changes in initial starting point, whereas amplitude reproduction reflects a bias to reproduce location.

> "....the data are consonant with the equifinality characteristic of a mass-spring system. That is, despite changes in initial conditions (displacement of a limb to a new starting position) a mass-spring system will always reach an invariant final position or equilibrium as determined by its parameters."

Further, Kelso and Holt demonstrated that accuracy of movements was not affected by perturbations which again supports the mass-spring view.

Cooke and Eastman (1977) and Evarts and Granit (1976) have proposed fast acting feedback loops, acting in a closed loop manner, to account for these findings. However, Kelso and Holt (1980), using a wrist-cuff technique, demonstrated that performance in a localization task showed no significant difference between perturbed and non-perturbed trials, even in the absence of sensory feedback.

While the mass-spring theory of limb localization appears to account for many observed phenomena in movement, the applicability of this engineering analogy to the human muscular system is open to some dispute. Houk (1976) demonstrated that when loaded, skeletal muscle fails to demonstrate the same characteristic elastic properties of springs as suggested by Bizzi et al (1976, 1978); Polit and Bizzi (1979); Kelso and Holt (1980) and by earlier worker (Bernstein, 1947; Crossman and Goodeve, 1963). In fact, Houk (1976) demonstrated that the spring analogy to muscle breaks down if the muscle is stretched by only 1% of its original length. Houk goes on to propose that the important property of muscle in the control of limb localization is the property of 'stiffness' which is the function of length and tension.

This theory is well supported by evidence from neuromuscular physiology which has demonstrated the presence of fast acting feedback loops which may be responsible for adjusting stiffness of the muscle throughout movement (Garnett & Stephens, 1980;

Buller, Garnett & Stephens, 1980). Furthermore, many deafferentation studies demonstrate loss of fine motor coordination of deafferented limbs while gross accuracy is maintained. This observation led Glencross (1977) to propose a two tier model of movement control which is paralleled by the current theories of alpha-gamma coactivation as the means of movement control.

Clearly, therefore, while the 'mass-spring' has attracted a great deal of attention from psychologists, its enthusiastic reception must be tempered by a regard for the evidence from neuromuscular physiologists and engineers.

Summary and Conclusions

This chapter has presented a number of conceptual approaches to the theories of movement control. The early work of Fitts' (1954) emphasized an information processing approach to movement control. The theory stated that if repetitive movements of average amplitude are speeded up then each movement can provide less information and, therefore, variability in the movement or its duration will increase. Accounting for this theory, Crossman and Goodeve (1963) proposed a system of control based on the continual monitoring of feedback. The most contradictory evidence to this point of view comes from study of deafferentation in which decrements in performance were not noted in the absence of sensory feedback.

Schmidt et al (1978, 1979) in examining the locus of variability in movement, proposed an impulse timing representation of movement control. Such a theory suggested that variability in

movement endpoint was due to variability in force production and time production mechanisms. However, while Fitts' law is seen to hold for longer amplitude, slow movements, Schmidts law accomodates only short duration, ballistic type movements.

The existence of two, independent methods of movement control would appear excessively complicated. Most recent studies, especially those concerned with deafferentation have favoured a method of movement control which takes advantage of the passive elastic properties of the agonist and antagonist muscles. The mass-spring theory proposes that final limb position is an equilibrium point based on the firing rate and recruitment of motor units, the length tension properties of the muscles involved and the passive elastic properties of the loaded muscles. This theory was first proposed by Crossman and Goodeve (1963) and has recently been supported by the work of Bizzi et al. (1974, 1978); Polit and Bizzi (1979) and Kelso and Holt (1980). Such a theory accomodates the observations that final endpoints can be achieved by a number of varying trajectories, velocities and forces. This view of movement control and the evidence to support it, are particularly damning for the impulse timing view of control. Impulse timing hypothesises that if the mass of a limb is increased then the time production mechanism will meter out the same length of time and since the force is maintained then the limb will fall short of the target. However, this situation is not observed as increasing the mass of the limb (Polit & Bizzi, 1979) does not prevent acquisition of the target. This supports the mass-spring view of control.

Although the mass-spring theory of movement control is regarded, even by Schmidt and McGown (1980) as damaging to the motor output variability theory, one or two questions still remain. Polit and Bizzi (1979) have proposed that although the mass-spring theory accounts for correct positioning of limbs, it must be accompanied by a mechanism which controls limb velocity. It is proposed that these mechanisms underlying limb movement are independent but act in parallel.

Reaction time is generally accepted as a measure of processing demands and variations in reaction time due to manipulation of response parameters indicate the degree to which a parameter is a feature in response programming. The only response parameter consistently seen to affect reaction time has been movement time (Klapp et al , 1974; Kerr, 1978). However, Falkenberg and Newell (1980) have shown that these variations in reaction time could equally be attributed to variations in average velocity. As a result, the possibility still remains that the system is programmed around the force-time or impulse requirements of the response, since Schmidt et al (1978) demonstrated that reaction time varied not only with velocity but also with impulse force.

It could be that the theory of Schmidt et al although not speaking directly to this point, account for the proposed parallel process governing velocity described by Polit and Bizzi (1979).

APPENDIX B

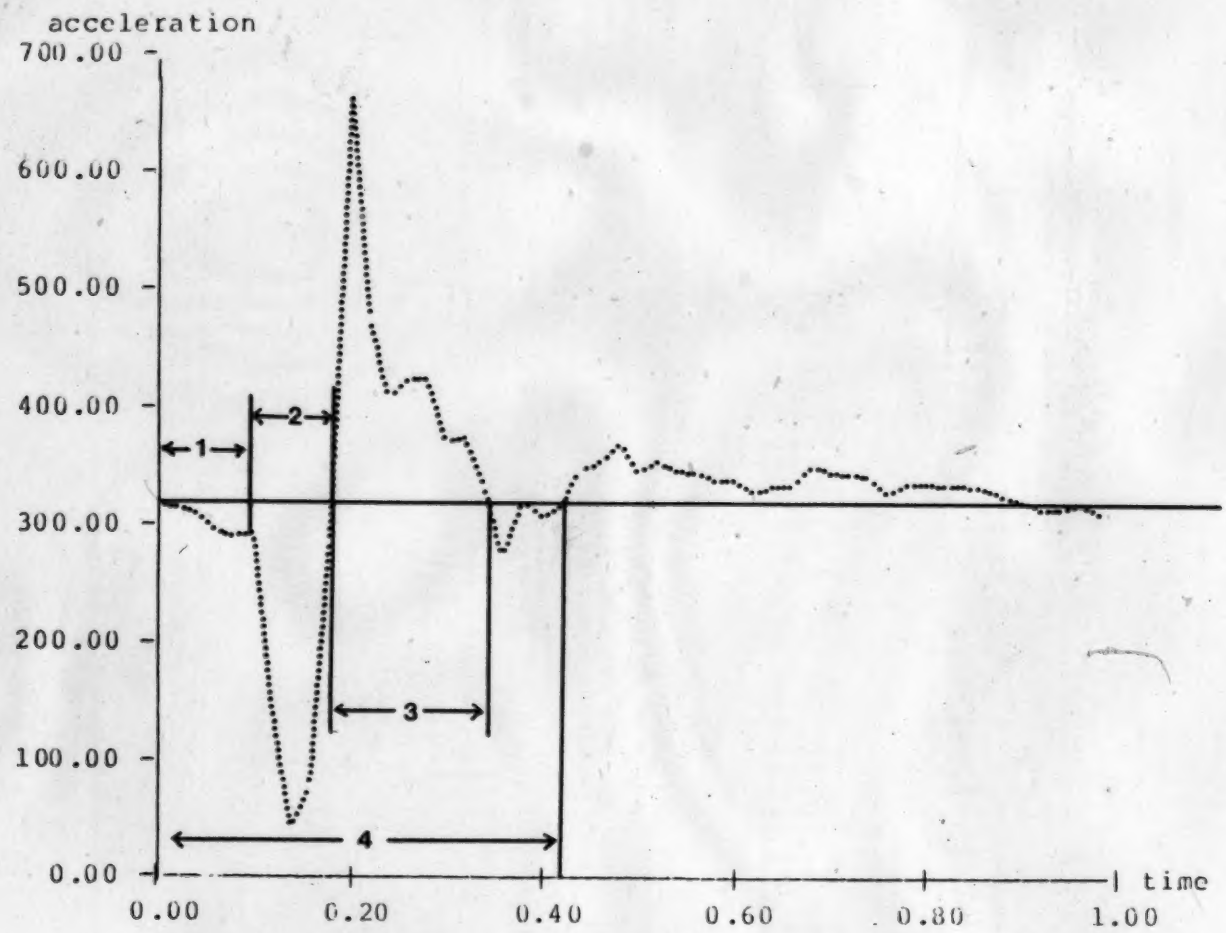
Figure A shows the rate of change of velocity with time as represented in digital values per second. This data was obtained from the accelerometer during one trial from one subject performing a 40 cm. movement. Digital values have been adjusted by subtracting 200 from each value in order to reduce the length of the Y axis. 312 digital values, therefore, represents zero acceleration. Values below 312 represent acceleration, while those above 312 represent deccelera-tion. Due to noise in the system and the extreme sensitivity of the accelerometer, a small fluctuation around the zero value is present even when the accelerometer is at rest.

Time has been partitioned into four units:

1. Represents time from the presentation of the signal to move to the initiation of the response by the subject. This is, therefore, a measure of reaction time.

2. Represents the time during the movemnet in which the limb undergoes acceleration. This is the time of acceleration. The area under the curve bounded by the two lines of 2 represents the accelerative impulse.

3. Represents the time during the movement in which the limb undergoes decceleration. This is the time of decceleration. The area under the curve bounded by the two lines of 3 represents the decelerative impulse.



acceleration as a function of time

Figure A

Digitally coded analog data from accelerometer for one trial for a single subject performing a 40 cm. movement.

4. Represents the time from the presentation of the signal to move to the completion of the response by the subject. This is a measure of the total movement time.

The computer was programmed to calculate the variables listed for each trial completed under each amplitude of movement. Results were printed in tabular form.

Figure B shows the displacement as measured in digital values over time for a single trial by one subject performing a 40 cm. movement. The data has been partitioned into two units:

1. Represents the distance in digital values that the subject moved prior to the initiation of a correction.

2. Represents the distance moved in digital values following a correction.

The computer was programmed to calculate these distances for each trial performed for each amplitude of movement.

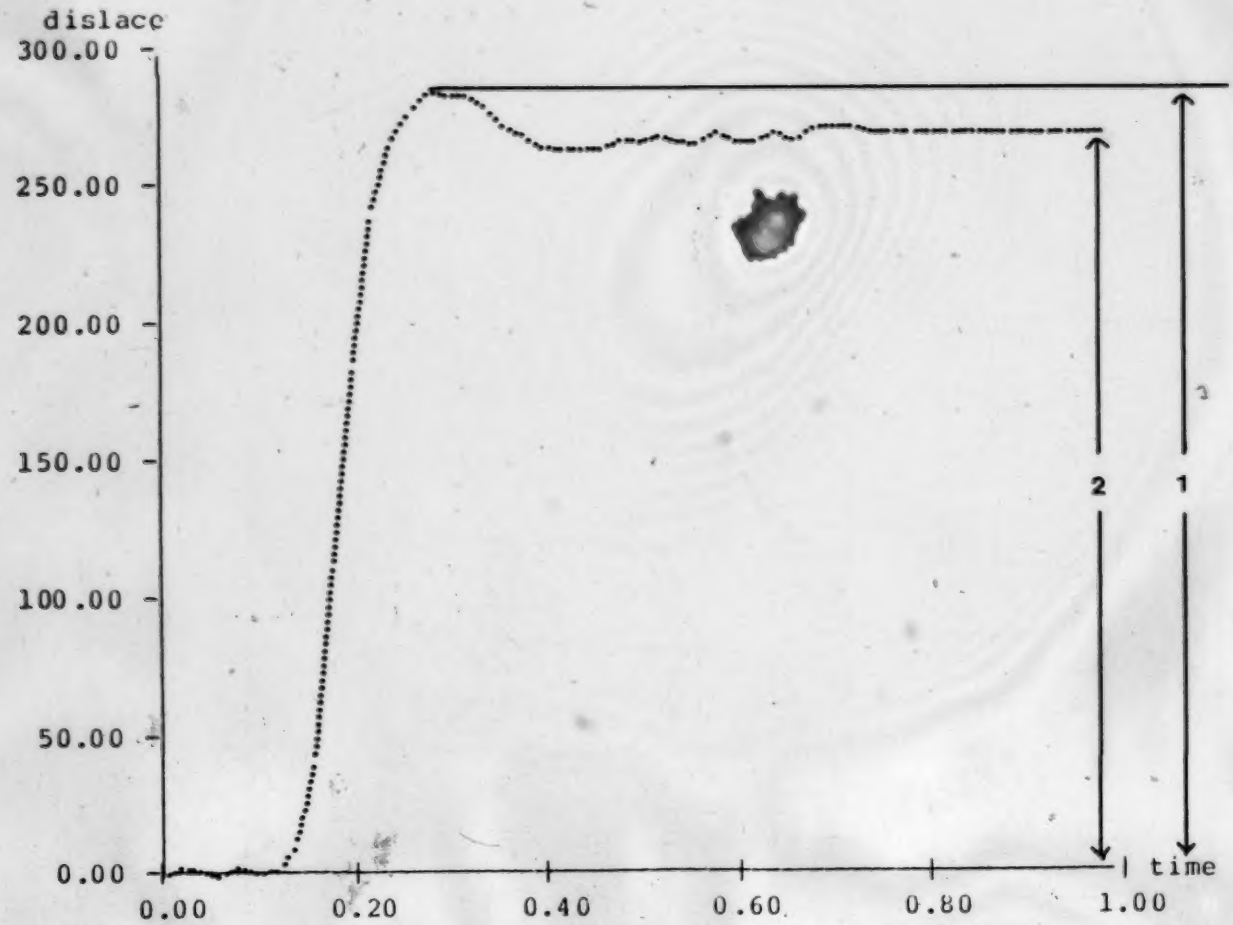


Figure B

Shows displacement in digital values for a subject performing a single trial of amplitude 40 cm.

APPENDIX C

Table

Analysis of Variance

Experiment 1 Variable: Reaction Time

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	1	2011376.0	22.00*
AMPLITUDE (A)	2	43368.000	3.00
GP X A	2	33416.000	2.31
TRIALS (T)	19	3238.7368	1.25
GP X T	19	2654.3157	1.02
A X T	38	2013.4736	0.92
GP X A X T	38	2086.3157	0.95
SUBJECTS (S)	19	192474.00	
GP X S	18	91424.000	
GP X A X S	36	14474.219	
GP X T X S	342	2600.5140	
GP X A X T X S	684	2185.1460	

Table

Analysis of Variance

Experiment 1 Variable: Time of Acceleration

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	14005.500	5.94*
AMPLITUDE (A)	2	47720.000	46.05*
GP X A	4	717.25000	0.69
TRIALS (T)	19	265.31367	0.97
GP X T	38	197.63158	0.72
A X T	38	288.52612	1.08
GP X A X T	76	215.77631	0.81
SUBJECTS (S)	29	3161.2700	
GP X S	27	2358.0000	
GP X A X S	54	1036.3500	
GP X T X S	513	274.27000	
GP X A X T X S	1026	265.93000	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Time of Deceleration

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	93208.000	4.84*
AMPLITUDE (A)	2	110776.00	8.21*
GP X A	4	2459.9990	0.18
TRIALS (T)	19	2189.4736	0.34
GP X T	38	8003.7891	1.23
A X T	38	5663.5781	0.91
GP X A X T	76	5367.5781	0.86
SUBJECTS (S)	29	24354.650	
GP X S	27	19253.333	
GP X A X S	54	13494.219	
GP X T X S	513	6492.2200	
GP X A X T X S	1026	6206.7900	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Distance Moved Prior to Correction

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	6728.0000	0.93
AMPLITUDE (A)	2	4341160.0	1479.9*
GP X A	4	536.00000	0.18
TRIALS (T)	19	946.52612	1.25
GP X T	38	693.05249	0.91
A X T	38	906.10522	1.15
GP X A X T	76	950.10522	0.11
SUBJECTS (S)	29	7163.5860	
GP X S	27	7195.8500	
GP X A X S	54	2933.3300	
GP X T X S	513	758.20600	
GP X A X T X S	1026	787.94500	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Distance Moved Following Correction

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	1512.0000	0.55
AMPLITUDE (A)	2	4813840.0	7110.1 *
GP X A	4	980.00000	1.45
TRIALS (T)	19	103.57893	0.53
GP X T	38	98.526306	0.50
A X T	38	234.10526	1.19
GP X A X T	76	261.69000	1.33
SUBJECTS (S)	29	2680.2700	
GP X S	27	2766.8100	
GP X A X S	54	677.03000	
GP X T X S	513	197.17700	
GP X A X T X S	1026	196.19000	

* $p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Accelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	724.836×10^6	7.74*
AMPLITUDE (A)	2	187.800×10^7	60.32*
GP X A	4	31401984.0	1.01
TRIALS (T)	19	5200008.00	1.19
GP X T	38	4566069.00	1.03
A X T	38	5357244.00	1.21
GP X A X T	76	5167481.00	1.16
SUBJECTS (S)	29	2743766.00	
GP X S	27	93658832.0	
GP X A X S	54	31187696.0	
GP X T X S	513	4436630.00	
GP X A X T X S	1026	4444391.00	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Decelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	886.01×10^6	1.72
AMPLITUDE (A)	2	428.84×10^7	31.22*
GP X A	4	29163520.0	0.21
TRIALS (T)	19	30156896.0	0.56
GP X T	38	42531136.0	0.79
A X T	38	41296288.0	0.84
GP X A X T	76	37907392.0	0.77
SUBJECTS (S)	29	1621202.40	
GP X S	27	514799620.0	
GP X A X S	54	137342820.0	
GP X T X S	513	53545584.00	
GP X A X T X S	1026	49029536.00	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: S.D. Duration of Accelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	138.630	5.83*
AMPLITUDE (A)	2	59.1750	2.248
GP X A	4	15.4830	0.58
SUBJECTS (S)	29	31.6900	
GP X S	27	23.7690	
GP X A X S	54	26.3220	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: S.D. Duration of Decelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	11292.75	4.902*
AMPLITUDE (A)	2	107.7500	0.062
GP X A	4	710.0780	0.407
SUBJECTS (S)	29	2923.580	
GP X S	27	2303.630	
GP X A X S	54	1745.890	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: S.D. Accelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	1021717.00	2.036
AMPLITUDE (A)	2	2821120.00	9.482*
GP X A	4	38400.0000	0.128
SUBJECTS (S)	29		
GP X S	27	501826.130	
GP X A X S	54	299633.750	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: S.D. Decelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2		1.369
AMPLITUDE (A)	2		4.981*
GP X A	4		0.491
SUBJECTS (S)	29		
GP X S	27		
GP X A X S	54		

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: S.D. Distance Moved Prior to Correction

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	9.24800	0.122
AMPLITUDE (A)	2	1607.19	26.532*
GP X A	4	57.3400	0.947
SUBJECTS (S)	29	70.9400	
GP X S	27	75.5130	
GP X A X S	54	60.5740	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: S.D. Distance Moved Following Correction

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	2.1780	0.233
AMPLITUDE (A)	2	220.41	20.926*
GP X A	4	5.8180	0.552
SUBJECTS (S)	29	8.8490	
GP X S	27	9.3440	
GP X A X S	54	10.533	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Reaction Time

SOURCE	DF	MS	F
AMPLITUDE (A)	2	14521.9	2.10
PERIPHERAL TARGET WIDTH (PTW)	2	13550.5	1.129
SUBJECTS (S)	4	93988.2	
A X PTW	4	13082.1	1.816
A X S	8	6914.04	
PTW X S	8	11993.9	
A X PTW X S	16	7201.81	

Table

Analysis of Variance

Experiment 2 Variable: Duration of Accelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	1844.796	18.915*
PERIPHERAL TARGET WIDTH (PTW)	2	291.4450	5.985*
SUBJECTS (S)	4	26.44100	
A X PTW	4	113.6640	1.344
A X S	8	97.52900	
PTW X S	8	48.69100	
A X PTW X S	16	84.57200	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Duration of Decelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	7946.670	7.029*
PERIPHERAL TARGET WIDTH (PTW)	2	224.8090	1.137
SUBJECTS (S)	4	1603.608	
A X PTW	4	1233.877	2.820
A X S	8	1130.548	
PTW X S	8	197.7250	
A X PTW X S	16	437.4260	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Movement Time

SOURCE	DF	MS	F
AMPLITUDE (A)	2	41595.73	5.213*
PERIPHERAL TARGET WIDTH (PTW)	2	18749.68	1.232
SUBJECTS (S)	4	136598.0	
A X PTW	4	12177.49	0.578
A X S	8	7976.488	
PTW X S	8	15216.74	
A X PTW X S	16	6069.438	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Accelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	57522718.0	45.92*
PERIPHERAL TARGET WIDTH (PTW)	2	2520564.00	2.789
SUBJECTS (S)	4	19618000.0	
A X PTW	4	989102.000	1.481
A X S	8	1252668.00	
PTW X S	8	903544.000	
A X PTW X S	16	667482.000	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Decelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	145684050	6.864*
PERIPHERAL TARGET WIDTH (PTW)	2	15866323.0	1.746
SUBJECTS (S)	4	120411130	
A X PTW	4	35478570.0	3.252*
A X S	8	21223240.0	
PTW X S	8	9089092.00	
A X PTW X S	16	10909311.0	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Distance Moved Prior to Correction

SOURCE	DF	MS	F
AMPLITUDE (A)	2	98916.92	159.290*
PERIPHERAL TARGET WIDTH (PTW)	2	946.8380	3.102*
SUBJECTS (S)	4	1386.915	
A X PTW	4	441.2110	2.928
A X S	8	620.9810	
PTW X S	8	305.1380	
A X PTW X S	16	150.652	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Distance Moved Following Correction

SOURCE	DF	MS	F
AMPLITUDE (A)	2	109572.1	239.430*
PERIPHERAL TARGET WIDTH (PTW)	2	506.621	1.813
SUBJECTS (S)	4	284.961	
A X PTW	4	151.057	2.403
A X S	8	457.626	
PTW X S	8	279.433	
A X PTW X S	16	62.8200	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: S.D. Distance Moved Prior to Correction

SOURCE	DF	MS	F
AMPLITUDE (A)	2	1979.77	11.96*
PERIPHERAL TARGET WIDTH (PTW)	2	40.6350	5.05*
SUBJECTS (S)	4	228.753	
A X PTW	4	234.735	2.44
A X S	8	165.431	
PTW X S	8	8.04800	
A X PTW X S	16	96.2300	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: S.D. Duration of Accelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	748.480	1.276
PERIPHERAL TARGET WIDTH (PTW)	2	715.765	2.375
SUBJECTS (S)	4	112.673	
A X PTW	4	698.384	2.039
A X S	8	586.551	
PTW X S	8	301.388	
A X PTW X S	16	342.348	

Table

Analysis of Variance

Experiment 2 Variable: S.D. Duration of Decelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	8042.14	5.539*
PERIPHERAL TARGET WIDTH (PTW)	2	617.765	1.746
SUBJECTS (S)	4	3767.49	
A X PTW	4	2853.16	2.215
A X S	8	1451.84	
PTW X S	8	353.744	
A X PTW X S	16	1288.28	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: S.D. Accelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	2844753.0	4.68*
PERIPHERAL TARGET WIDTH (PTW)	2	721466.00	3.47
SUBJECTS (S)	4	62335.000	
A X PTW	4	527763.0	1.87
A X S	8	607734.0	
PTW X S	8	208001.0	
A X PTW X S	16	281419.0	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: S.D. Decelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	11460300.0	6.53*
PERIPHERAL TARGET WIDTH (PTW)	2	8303421.00	1.16
SUBJECTS (S)	4	67239232.0	
A X PTW	4	40652767.0	2.24
A X S	8	17561313.0	
PTW X S	8	7163444.00	
A X PTW X S	16	18118271.0	

*$p < .05$

APPENDIX D

Raw Data from Experiments One and Two

The data for experiment one is organized in the following manner:-

Column 1	Treatment Condition
Columns 2-3	Amplitude of Movement
Columns 4-5	Subject Number
Columns 6-7	Trial Number
Columns 9-11	Reaction Time
Columns 13-15	Duration of Accelerative Impulse
Columns 17-19	Duration of Decelerative Impulse
Columns 21-23	Movement Time
Columns 25-27	Distance Moved Without Correction
Columns 29-31	Distance Moved Following Correction
Columns 33-37	Accelerative Impulse
Columns 39-43	Decelerative Impulse

For Experiment Two data will be found in the same columns. Columns 1-6 are as follows:-

Column 1	Subject Number
Columns 2-3	Amplitude of Movement
Column 4	Peripheral Target Width
Columns 5-6	Trial Number

EXPERIMENT 1

1100101	070	046	086	230	071	068	04010	07773
1100102	070	034	086	210	068	063	02268	07272
1100103	072	070	078	266	085	069	04254	06926
1100104	098	060	062	248	068	068	04994	04463
1100105	072	036	104	234	072	068	02278	09275
1100106	092	048	056	266	057	057	03082	04857
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2101304	238	050	030	338	060	067	02653	00733
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2401817	170	062	140	416	244	236	05577	14373
2401818	170	056	068	314	252	254	09450	12022
2401819	152	068	084	346	258	258	10043	10675
2401820	170	052	224	466	251	253	06386	20821

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2101903	200	070	080	448	085	058	04284	09211
2101904	182	062	074	452	093	055	04473	06200
2101905	160	056	100	340	069	044	03507	08764
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2101907	172	080	078	374	091	048	04911	07871
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2101910	182	062	096	426	086	044	04538	10125
2101911	260	056	094	486	077	041	04806	10797
2101912	216	060	096	392	073	049	04267	10050
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2101916	128	052	080	342	067	044	03136	08307
2101917	216	048	078	366	078	049	03083	09810
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2201908	218	084	098	420	133	124	06819	08642
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2201918	166	084	082	434	122	106	05447	07410
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2401903	428	052	086	684	236	201	07799	04258
2401904	362	056	136	628	289	249	08346	15514
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3202205	058	030	376	110	143	06409	01184
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3202213	052	076	482	146	141	04371	07136
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3102514	044	112	386	065	058	02007	11358
3102515	036	080	870	062	057	01539	06452
3102516	052	108	486	071	063	03717	08924
3102517	030	136	464	056	054	01364	11849
3102518	042	044	802	064	065	03290	02527
3102519	038	052	382	086	077	02490	06911
3102520	048	044	808	081	056	03200	05448
3202501	096	146	366	118	117	10796	24720
3202502	060	048	270	104	115	05537	02551
3202503	044	032	264	102	118	04452	01528
3202504	060	096	446	142	131	05673	07541
3202505	100	034	240	111	117	08730	01583
3202506	062	102	328	116	116	04145	05615
3202507	066	062	294	119	127	06676	01940
3202508	114	066	396	134	123	10664	03680
3202509	064	030	366	099	113	04691	01110
3202510	092	068	296	139	139	09400	03837
3202511	122	056	348	139	137	17585	04274
3202512	076	062	908	124	129	08650	04298
3202513	074	052	312	104	115	04743	03055
3202514	088	034	386	120	120	11293	03319
3202515	064	044	902	132	129	06172	04543
3202516	102	050	372	137	136	14365	02679
3202517	092	054	422	136	136	11073	04724
3202518	090	050	448	149	148	14210	04997
3202519	086	056	622	143	131	11902	03136
3202520	050	092	554	137	121	05725	07954
3402501	080	032	400	188	241	10026	01110
3402502	092	034	430	204	233	11637	02637
3402503	098	036	474	221	250	10928	01583
3402504	076	110	530	251	237	06996	15436
3402505	074	128	572	259	250	06298	18029
3402506	102	074	842	256	253	11951	07532
3402507	082	034	448	196	232	09820	01328
3402508	082	112	896	246	242	11663	11997
3402509	104	092	502	260	236	12920	11241
3402510	088	100	556	252	242	10585	11384
3402511	086	094	488	253	230	10205	14530
3402512	096	108	468	251	251	09665	14749
3402513	086	088	513	245	246	11876	08273
3402514	080	110	480	266	254	11552	14872
3402515	072	118	564	246	222	05200	17653
3402516	080	086	460	254	251	10737	09762
3402517	104	074	470	262	253	13885	11904
3402518	100	064	460	259	259	11881	09651
3402519	080	110	548	255	234	08204	15520
3402520	080	032	424	185	222	09113	04504

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3102602	054	056	318	092	079	05836	07219
3102603	048	030	178	067	076	03177	00495
3102604	048	078	326	083	074	02522	05290
3102605	090	066	372	096	067	09620	09023
3102606	048	030	284	073	085	02900	01659
3102607	062	030	252	084	093	06947	01164
3102608	066	050	244	085	085	03534	02741
3102609	062	066	378	067	061	03023	03157
3102610	058	064	262	077	066	03829	05320
3102611	054	058	270	086	078	04231	05523
3102612	062	072	322	083	068	03599	07567
3102613	070	048	274	075	075	04367	03164
3102614	054	058	312	081	060	03262	05542
3102615	046	048	244	086	086	04170	02234
3102616	048	064	306	080	070	02912	05824
3102617	038	046	320	088	066	02874	03616
3102618	072	050	236	086	086	05718	02192
3102619	056	066	280	093	081	04388	07488
3102620	066	046	664	093	080	07806	02782
3202601	068	048	356	117	129	05540	02290
3202602	066	054	290	117	125	04655	02897
3202603	074	036	232	093	112	02560	01690
3202604	074	030	232	118	145	06615	00685
3202605	094	048	306	116	128	08780	00676
3202606	072	030	240	090	115	04328	01142
3202607	066	048	328	108	135	02923	01608
3202608	074	030	286	103	132	04465	00268
3202609	066	038	258	120	142	04390	01142
3202610	062	032	332	084	106	03229	00402
3202611	052	096	348	146	135	03860	07883
3202612	080	052	282	142	146	07454	05171
3202613	042	030	210	103	136	04147	00918
3202614	072	070	330	154	148	05789	06091
3202615	052	048	192	116	124	02824	05829
3202616	056	060	270	127	129	04035	06476
3202617	072	074	650	139	135	05366	03256
3202618	064	068	582	133	141	06379	06137
3202619	066	032	248	114	131	05494	00824
3202620	064	036	236	103	117	05730	02843
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3402602	106	360	998	233	251	15125	78091
3402603	076	060	310	243	243	10298	06045
3402604	074	128	408	259	257	09281	13326
3402605	068	106	396	259	259	07599	12286
3402606	098	052	300	247	282	12532	04107
3402607	086	068	340	243	243	14460	07786
3402608	064	116	522	278	246	10752	11542
3402609	092	076	390	259	259	11323	10776
3402610	084	102	374	267	263	08307	11887
3402611	098	100	392	282	251	13191	11840
3402612	092	084	320	276	270	11837	13163
3402613	084	096	374	287	276	12483	12620
3402614	088	082	474	263	244	11997	08333
3402615	064	096	362	251	251	09587	10716
3402616	084	092	904	301	256	11235	13266
3402617	084	134	460	256	243	10944	16507
3402618	056	108	470	281	271	09248	15444
3402619	080	034	274	179	234	11724	01230
3402620	100	314	998	246	246	13227	21051

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3102702	066	072	714	074	064	03150	03343
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3102705	060	074	374	072	060	02652	04475
3102706	046	106	340	070	060	02344	06262
3102707	062	052	472	074	062	05054	04233
3102708	042	068	328	056	057	01471	03110
3102709	062	104	450	077	070	03371	06108
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3102711	078	046	290	077	077	07360	02947
3102712	056	086	442	079	066	03498	04335
3102713	056	042	280	059	065	02263	02285
3102714	062	038	340	064	071	03584	02648
3102715	058	064	378	072	068	03568	04585
3102716	072	076	598	063	055	03223	03654
3102717	064	062	402	080	069	03587	04819
3102718	044	092	618	069	063	02486	06045
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3202702	070	080	662	135	135	04653	04099
3202703	066	068	754	121	134	04057	07397
3202704	072	064	454	144	127	07547	05590
3202705	050	124	362	149	138	03815	13201
3202706	066	094	388	135	137	05529	08448
3202707	084	052	476	123	123	08017	04342
3202708	076	080	374	138	136	05527	07943
3202709	068	140	660	123	116	05368	13826
3202710	070	340	996	121	127	09610	53268
3202711	066	100	650	146	144	06019	08833
3202712	076	092	488	124	121	05937	07461
3202713	074	080	804	139	139	08443	04767
3202714	078	036	442	125	139	06124	05255
3202715	076	072	696	158	126	11252	04192
3202716	074	302	996	122	124	08140	28709
3202717	060	062	586	126	126	06870	04150
3202718	050	254	962	125	119	03365	08392
3202719	070	090	746	155	131	09618	03800
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3402702	078	030	700	163	241	10152	00221
3402703	090	134	490	242	244	09559	10027
3402704	080	088	396	245	251	06259	08606
3402705	080	438	832	245	243	07605	52302
3402706	072	084	516	226	241	09858	07348
3402707	082	082	662	266	253	12507	10112
3402708	078	030	346	184	221	09067	00557
3402709	082	128	590	240	236	06798	12662
3402710	086	128	556	234	238	07517	13339
3402711	078	350	998	248	246	06951	55069
3402712	058	178	416	240	232	05151	14697
3402713	066	082	354	246	249	09302	07737
3402714	076	142	472	252	248	08623	13257
3402715	064	162	576	241	236	06299	14347
3402716	080	040	340	192	221	07489	02980
3402717	076	142	484	253	242	07345	14208
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3402719	072	144	480	233	232	08257	13842
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3102803	070	048	646	081	066	07037	02808
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3102805	054	062	536	083	077	03158	05283
3102806	068	042	712	093	065	08757	02240
3102807	060	066	860	090	066	02940	06200
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3102812	062	066	518	090	062	04288	02788
3102813	042	110	502	082	070	01793	08602
3102814	030	058	556	061	056	00371	02615
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3102816	042	112	472	071	061	01712	08465
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3102820	056	066	442	082	065	03222	05791
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3202802	144	076	976	116	127	07756	01738
3202803	094	108	368	117	118	03644	03074
3202804	078	092	760	127	131	04360	05496
3202805	084	034	272	085	110	05523	00491
3202806	102	112	428	128	125	02312	06368
3202807	034	206	410	118	115	00963	10929
3202808	050	136	276	131	126	03606	12460
3202809	062	038	328	095	124	02572	01409
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3202813	098	040	434	134	134	09123	01958
3202814	052	052	222	091	113	01577	03235
3202815	064	136	400	131	118	04215	10765
3202816	064	120	372	139	132	02560	11227
3202817	084	038	242	108	124	04126	00892
3202818	050	134	924	139	130	01765	12179
3202819	058	048	238	099	118	02649	02448
3202820	068	098	514	126	125	03886	09641
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3402802	104	032	300	208	232	10451	01280
3402803	108	116	390	247	247	08589	05717
3402804	062	046	254	196	234	05298	01628
3402805	062	030	238	163	210	04355	00282
3402806	084	074	330	252	261	06242	04728
3402807	078	030	424	184	224	05263	02360
3402808	088	034	414	216	246	09869	01795
3402809	070	156	620	262	243	06552	13217
3402810	094	128	436	271	267	07075	09973
3402811	104	076	404	241	241	09556	05307
3402812	082	030	348	185	219	06203	01702
3402813	134	056	404	230	243	11144	04142
3402814	090	030	362	202	240	06408	01347
3402815	116	090	392	260	262	09204	06360
3402816	096	070	356	249	259	09986	04998
3402817	092	070	408	256	256	11137	05156
3402818	094	124	574	265	255	07253	09592
3402819	074	038	334	204	244	06618	01835
3402820	090	100	406	264	262	09929	05073

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3102902	076	096	484	058	049	08041	17132
3102903	068	098	446	065	046	04412	23905
3102904	060	088	556	097	056	05588	07599
3102905	062	098	550	068	050	06630	16129
3102906	050	070	546	089	061	02999	09399
3102907	060	070	538	073	057	05606	09858
3102908	064	096	420	061	049	02937	15257
3102909	064	084	496	069	046	02534	06976
3102910	060	080	482	073	043	04537	10392
3102911	036	038	330	072	089	02339	00845
3102912	062	056	524	082	045	04738	08186
3102913	050	080	468	068	041	02628	10388
3102914	052	074	496	076	045	03984	07828
3102915	068	046	540	095	063	06081	09116
3102916	072	072	508	084	058	07124	09361
3102917	060	122	514	059	053	06198	19069
3102918	060	074	614	071	054	04877	08103
3102919	070	056	582	095	067	03606	15227
3102920	054	030	378	064	070	04397	00244
3202901	080	080	668	175	118	09480	14881
3202902	074	076	604	176	136	11183	09330
3202903	068	070	532	140	116	07103	11508
3202904	056	090	572	153	105	05864	13197
3202905	056	108	526	152	113	04985	19883
3202906	062	094	536	156	130	05542	13593
3202907	068	050	560	167	111	07283	10645
3202908	096	040	456	163	143	10398	08952
3202909	064	056	904	174	124	06677	06501
3202910	064	078	432	159	145	04550	10300
3202911	066	074	534	178	105	06225	11650
3202912	064	094	460	149	108	05916	16923
3202913	060	096	494	139	110	08208	14947
3202914	058	094	492	149	101	06395	15086
3202915	030	126	630	144	116	06723	22910
3202916	060	100	550	157	133	08041	17330
3202917	064	100	544	138	101	05846	16124
3202918	058	100	440	144	109	05375	18526
3202919	080	076	570	174	124	09627	09985
3202920	030	128	520	145	110	04972	15795
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3402903	078	112	614	248	222	10052	15319
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3402905	070	106	620	267	232	06908	18417
3402906	062	142	614	248	222	05254	20144
3402907	078	096	632	271	215	08457	15150
3402908	080	100	732	249	217	08787	15579
3402909	074	100	578	282	235	07798	13964
3402910	076	102	552	263	228	08355	17053
3402911	092	096	622	278	226	08947	13729
3402912	078	146	606	253	240	05284	21329
3402913	078	098	642	252	219	09500	12835
3402914	078	108	676	266	231	08512	16603
3402915	068	132	588	250	219	07372	20689
3402916	068	112	652	248	225	05532	18167
3402917	086	104	718	267	240	07206	15195
3402918	064	090	652	284	237	07144	11439
3402919	106	042	868	293	235	16082	05128
3402920	098	072	630	260	232	13376	13449

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3103003	050	106	770	079	068	02855	10544
3103004	068	076	546	088	063	06351	05920
3103005	080	330	970	058	067	03410	17337
3103006	064	080	778	084	063	02995	09724
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3103008	072	066	768	094	067	06946	04329
3103009	056	074	604	091	065	04821	07723
3103010	058	072	996	101	066	06912	07008
3103011	042	090	576	077	068	02020	07697
3103012	064	080	688	083	061	01980	11362
3103013	070	070	556	092	069	05450	06372
3103014	056	046	732	091	063	04173	03570
3103015	070	118	576	075	062	02686	10123
3103016	058	046	640	088	063	05770	03144
3103017	058	086	526	087	078	03055	10061
3103018	056	068	996	086	061	04360	05414
3103019	030	084	578	076	053	00908	09524
3103020	068	102	630	074	063	05757	13665
3203001	048	082	418	147	144	04496	08479
3203002	062	038	364	114	139	07077	01379
3203003	036	034	294	113	135	03386	01764
3203004	054	128	468	140	130	02483	12402
3203005	050	106	384	147	135	04124	13748
3203006	062	082	412	154	149	05840	07660
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3203008	048	084	344	145	145	04194	06051
3203009	048	116	560	137	128	03052	14493
3203010	062	102	436	148	127	04465	10559
3203011	040	082	902	151	148	03387	07207
3203012	054	066	528	156	131	04974	07239
3203013	052	104	530	153	136	04588	11806
3203014	054	082	530	151	118	04589	12123
3203015	052	106	514	154	123	04686	13212
3203016	050	096	958	158	123	04487	12275
3203017	056	074	936	143	125	05071	08425
3203018	050	078	522	155	130	04815	10119
3203019	058	074	412	147	128	05194	10088
3203020	048	104	486	147	116	04325	12472
3403001	082	030	362	198	242	07369	02220
3403002	060	206	562	243	240	05892	18258
3403003	082	122	664	252	259	05838	12404
3403004	086	106	732	273	251	06128	12171
3403005	072	102	996	266	242	07159	10423
3403006	080	112	624	265	238	06896	12239
3403007	136	130	562	269	261	06367	15043
3403008	084	060	498	248	263	04906	08492
3403009	078	144	606	263	256	03987	17969
3403010	084	078	374	271	271	08290	08488
3403011	076	042	342	243	264	07896	05683
3403012	074	104	376	264	259	05990	15455
3403013	088	098	578	271	256	10938	10148
3403014	084	096	946	256	246	06725	11208
3403015	082	150	528	265	251	07342	13667
3403016	080	092	458	254	255	07464	10123
3403017	062	117	880	259	241	05793	13544
3403018	064	128	456	254	249	04583	14942
3403019	060	116	680	264	244	06706	10497
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EXPERIMENT 2

110101	400	062	066	564	078	064	03375	07154
110102	434	068	056	618	100	066	06761	06630
110103	292	056	072	476	101	063	03960	11274
110104	338	046	088	494	079	064	02945	11231
110105	408	068	066	602	088	059	06033	06051
110106	432	066	064	742	101	057	05714	06737
110107	504	078	078	824	098	061	07043	08607
110108	448	066	060	624	108	078	06442	10584
110109	448	054	088	640	085	064	02799	08143
110110	388	056	098	566	078	064	05732	14376
110111	438	052	090	610	096	077	03805	08198
110112	392	082	088	596	102	082	06974	10008
110113	426	064	090	604	079	069	03369	06692
110114	440	068	116	644	086	081	06307	16167
110115	528	064	350	942	060	060	05226	42810
110116	518	062	074	704	108	073	05191	08696
110117	564	056	098	744	085	070	02737	10727
110118	436	032	030	522	023	068	02407	03279
110119	484	030	030	564	027	064	01297	03120
110120	542	068	064	722	092	055	03662	09701
110201	488	052	078	642	074	058	04057	09567
110202	530	056	064	862	084	067	07046	03802
110203	438	058	100	616	068	061	02767	10952
110204	464	098	096	686	086	071	07646	10813
110205	586	076	068	778	099	072	08170	04570
110206	512	070	066	876	090	058	06096	05862
110207	490	058	078	778	081	050	04721	06923
110208	642	060	060	820	085	058	04538	06194
110209	600	074	066	784	086	061	08240	04264
110210	610	066	060	786	095	071	07312	04428
110211	656	034	102	812	073	060	00981	08545
110212	726	074	086	906	086	073	05733	07122
110213	604	066	050	786	079	053	07350	04199
110214	528	066	070	684	092	087	06736	06253
110215	584	054	080	740	071	062	02982	08590
110216	804	070	066	982	098	083	05554	05446
110217	762	060	098	940	094	081	03756	08960
110218	492	070	066	678	098	071	06377	05713
110219	634	068	084	920	107	053	08483	07202
110220	514	074	062	706	090	061	08036	05037
110401	168	070	072	356	101	070	05214	06788
110402	310	062	062	856	100	064	05036	05149
110403	386	052	130	594	077	063	01939	12500
110404	222	060	148	450	081	072	05883	14754
110405	270	058	104	454	087	072	03283	09663
110406	324	084	322	750	072	072	09966	50299
110407	250	050	110	432	069	057	02307	13191
110408	254	068	066	440	112	079	06671	05967
110409	286	086	050	528	090	059	08367	04420
110410	390	062	084	586	096	072	06357	05048
110411	252	066	138	476	060	061	04675	14084
110412	314	064	066	464	109	100	05408	05289
110413	206	076	100	410	081	068	06478	11320
110414	312	062	078	508	085	058	02013	07966
110415	304	040	032	396	060	087	01698	03220
110416	338	068	068	532	076	053	03722	05634
110417	296	060	090	466	092	076	02207	11326
110418	332	068	086	518	120	090	06024	09938
110419	378	080	092	586	122	093	08992	12388
110420	254	036	030	340	048	068	02300	03180

120101	396	070	084	578	122	119	07732	07021
120102	468	062	174	746	119	119	07733	19095
120103	372	048	294	996	123	121	07225	36363
120104	410	060	390	996	134	131	07783	30360
120105	636	064	054	996	147	124	06975	05205
120106	458	056	078	592	138	138	05929	04785
120107	398	068	086	572	149	145	10133	08484
120108	490	064	038	612	124	145	08868	04062
120109	466	090	326	882	123	123	11663	55659
120110	440	076	070	606	159	157	08769	07988
120111	622	060	110	812	150	135	07178	14544
120112	488	058	052	810	124	118	04901	01944
120113	274	068	076	908	151	129	07277	10077
120114	534	074	388	996	127	127	09634	37741
120115	462	064	096	642	141	133	06984	08901
120116	430	058	296	998	131	126	08557	21690
120117	390	078	220	708	122	122	06510	21006
120118	474	066	296	856	114	118	06619	21541
120119	498	048	134	700	123	122	04815	22542
120120	640	060	124	844	140	130	05989	11392
120201	296	062	094	486	167	142	08422	13390
120202	322	088	084	996	174	120	09499	10797
120203	360	070	090	584	173	141	07087	10446
120204	342	078	094	648	159	118	07764	11754
120205	430	070	126	646	144	135	05877	11795
120206	448	074	106	628	155	155	07708	14590
120207	332	076	094	618	165	134	06735	07626
120208	380	058	128	648	158	126	05173	12137
120209	374	050	044	488	123	153	05052	04117
120210	300	074	364	758	123	122	05892	32114
120211	284	046	388	996	111	118	05386	73324
120212	338	034	182	572	127	121	03754	16733
120213	226	078	382	998	126	122	06493	70433
120214	362	082	374	996	117	117	07613	40490
120215	386	082	092	928	177	128	09646	11403
120216	392	074	138	624	162	149	05620	11980
120217	378	078	370	996	126	120	05257	40229
120218	350	070	134	576	149	139	04636	13973
120219	358	058	090	996	189	123	10276	07905
120220	312	076	102	568	183	142	07156	11924
120401	462	060	204	770	148	140	09296	21227
120402	208	040	100	404	142	132	04567	06628
120403	340	058	182	600	102	101	06371	21531
120404	428	072	266	766	128	128	09131	29182
120405	418	072	074	608	144	131	06475	09858
120406	270	060	470	820	130	130	05836	42568
120407	302	056	206	584	122	127	05585	19363
120408	244	074	074	418	163	158	07310	08290
120409	340	070	056	486	138	136	05899	08542
120410	420	068	080	590	142	137	08119	11114
120411	316	066	088	490	147	138	07090	13317
120412	270	080	078	580	151	123	09135	09547
120413	360	068	304	996	121	125	08036	39915
120414	326	074	074	494	151	140	08200	10932
120415	250	070	078	418	140	131	07086	12542
120416	334	070	072	496	148	142	10474	08240
120417	268	070	068	426	146	140	07539	07729
120418	290	076	100	840	157	125	08578	10003
120419	306	072	128	526	138	133	07144	24997
120420	328	058	418	996	128	126	08162	39341

140101	436	068	110	918	252	246	09110	14486
140102	536	090	130	778	250	246	10861	18046
140103	466	086	104	720	266	259	08911	12501
140104	384	076	080	999	263	215	12096	12177
140105	532	076	108	742	258	255	08878	14619
140106	524	086	086	716	270	264	08985	11937
140107	542	096	074	740	274	274	13292	10757
140108	456	068	112	658	260	260	09213	12417
140109	536	076	094	798	277	253	10761	11691
140110	552	094	112	778	272	263	09743	18089
140111	544	084	096	758	259	254	09175	14460
140112	674	068	130	904	272	240	09234	16564
140113	428	090	096	718	273	252	11489	12966
140114	426	076	032	554	182	230	09714	01172
140115	480	084	290	884	255	255	12705	47778
140116	462	072	030	584	169	221	07090	03350
140117	524	082	044	670	215	242	11509	03152
140118	338	090	066	514	245	246	09273	13945
140119	294	086	090	500	261	263	10552	13442
140120	452	082	102	780	259	245	08827	16299
140201	296	086	424	996	245	243	11555	37670
140202	386	074	030	510	154	212	12418	00210
140203	318	074	030	442	190	256	08970	01645
140204	270	076	128	900	265	252	08380	16949
140205	216	062	052	350	237	271	06968	05048
140206	236	076	042	374	219	267	10384	06049
140207	258	076	030	384	210	253	08070	00276
140208	264	094	128	626	277	233	08601	14425
140209	302	078	250	650	246	249	08471	45248
140210	346	092	082	996	295	249	14460	09791
140211	300	100	372	792	248	247	13837	39767
140212	276	090	484	872	247	247	10874	51502
140213	216	088	046	728	263	241	10159	05883
140214	156	088	122	396	292	267	13949	22941
140215	344	084	030	478	200	250	13194	03496
140216	306	082	078	486	297	295	14124	13036
140217	262	090	090	516	290	277	11636	10480
140218	192	104	030	346	268	244	13821	02010
140219	224	088	030	362	205	244	07782	03523
140220	258	084	122	490	281	270	09031	17932
140401	382	084	104	946	309	244	08975	17559
140402	304	076	030	430	206	256	09554	03159
140403	288	076	146	530	243	233	09482	32802
140404	302	080	140	542	282	272	09553	28028
140405	390	084	042	536	208	242	08096	04221
140406	208	088	120	416	263	263	09056	13530
140407	270	082	130	526	282	260	08844	16166
140408	240	084	036	380	233	272	07441	04465
140409	244	088	130	610	293	246	08918	18426
140410	426	068	150	678	279	259	06927	24105
140411	282	090	122	516	245	238	06669	14469
140412	350	078	368	996	255	244	10187	49458
140413	378	094	102	998	259	245	11471	12316
140414	298	076	140	580	254	236	09347	27928
140415	234	096	116	488	273	253	10266	17401
140416	398	086	136	638	291	276	09901	21391
140417	400	094	030	944	220	240	11614	01640
140418	288	078	284	998	248	246	08806	38572
140419	292	090	032	434	209	255	09918	03305
140420	446	070	124	672	286	276	09031	15847

210101	256	050	126	452	066	058	01832	08229
210102	264	044	100	466	076	051	02012	05962
210103	426	056	086	614	089	056	03534	08809
210104	078	034	112	244	073	073	01993	03989
210105	206	058	096	420	085	064	03078	04544
210106	166	060	094	366	073	049	03133	06224
210107	240	030	036	326	061	070	00495	02285
210108	224	048	032	314	066	081	01493	02007
210109	194	048	122	400	072	059	02132	07530
210110	358	030	050	438	059	059	00554	01598
210111	158	064	112	362	069	058	02617	06703
210112	270	060	106	458	073	062	02694	08374
210113	172	032	070	326	061	050	00587	04623
210114	116	040	112	288	064	057	01977	08692
210115	236	066	104	430	073	060	02957	08726
210116	180	052	104	366	074	061	02727	07564
210117	184	068	078	382	085	064	03185	04578
210118	314	030	092	482	063	056	00690	06531
210119	102	054	046	222	066	072	03034	02034
210120	218	032	070	320	044	059	00894	03387
210201	288	030	058	396	056	056	00457	04062
210202	312	320	030	682	060	082	08213	02286
210203	070	154	036	280	070	078	05270	01408
210204	224	054	030	328	052	069	01987	01601
210205	218	030	046	314	053	051	00111	01678
210206	206	054	030	310	048	066	03586	00621
210207	106	046	068	240	067	061	02078	05025
210208	176	056	036	288	062	068	03526	00637
210209	262	030	038	350	064	065	00161	02929
210210	148	030	050	248	067	061	00285	04836
210211	174	030	140	386	053	058	00499	03160
210212	228	030	054	740	060	047	00571	01447
210213	208	030	036	294	049	059	00529	02257
210214	432	064	036	554	059	066	02937	03457
210215	070	144	036	290	060	068	05277	01528
210216	234	065	040	348	056	065	01869	01203
210217	219	036	052	316	056	058	00111	01539
210218	106	045	059	258	069	060	02048	04923
210219	186	066	046	299	062	066	03546	01056
210220	149	036	060	242	062	061	01228	03436
210401	124	032	030	226	066	045	00835	00926
210402	108	078	032	238	051	064	01227	00196
210403	094	110	094	318	086	065	05781	05435
210404	226	138	122	818	072	052	04391	03026
210405	128	130	244	438	055	049	00210	08879
210406	112	068	034	234	073	085	03688	00871
210407	128	120	060	328	058	066	03181	01021
210408	156	030	064	270	032	059	00260	00300
210409	070	082	250	500	049	049	01983	14040
210410	112	104	052	288	059	068	02145	01340
210411	100	038	052	210	059	074	01665	02042
210412	070	100	048	724	052	056	04568	00970
210413	128	090	036	274	047	056	02578	00909
210414	096	036	064	216	032	042	00152	02780
210415	104	094	176	394	059	053	04118	08868
210416	094	030	150	294	052	060	00513	07218
210417	102	142	164	756	051	054	05279	02535
210418	226	138	122	818	072	052	04391	03026
210419	115	059	040	245	063	065	03221	01897
210420	156	060	065	290	062	064	01260	01230

220101	550	068	372	990	116	116	06975	71230
220102	134	062	040	256	128	145	06994	02878
220103	218	090	040	368	130	137	09332	01672
220104	228	080	088	528	151	114	06934	08845
220105	228	080	034	362	099	119	02608	01250
220106	376	086	030	512	098	126	05309	01288
220107	108	056	080	486	121	123	04905	05766
220108	126	070	086	302	140	129	04474	08204
220109	346	060	094	520	130	126	04952	08777
220110	344	082	034	480	092	116	02007	01670
220111	292	054	032	398	084	106	02509	01836
220112	132	068	362	582	115	119	03335	16639
220113	390	072	074	556	145	142	05224	07048
220114	120	056	092	288	133	128	03267	07832
220115	408	062	030	520	093	116	05143	00575
220116	274	056	114	510	130	106	02547	09539
220117	338	054	096	508	125	125	02109	11383
220118	364	060	424	874	119	120	04365	32917
220119	162	206	040	438	137	147	08736	04188
220120	126	060	080	318	134	115	05296	04794
220201	234	078	110	660	131	123	03595	08820
220202	138	060	168	432	123	117	02386	08398
220203	204	060	086	370	138	130	04090	07297
220204	200	074	106	422	131	114	04487	08718
220205	114	064	040	396	139	130	02047	09013
220206	234	034	140	688	128	104	00719	06978
220207	124	048	032	224	099	128	03773	00427
220208	256	076	116	518	139	123	03623	08904
220209	156	068	072	342	137	131	05869	04669
220210	076	114	074	372	146	121	06575	05266
220211	180	058	030	288	092	122	03459	00574
220212	192	066	064	342	112	123	03519	03143
220213	146	060	030	256	071	092	02404	00736
220214	218	094	094	406	137	137	04253	09246
220215	136	066	098	359	139	117	02234	09057
220216	130	070	134	356	139	131	04824	10025
220217	176	052	094	368	140	129	04197	07418
220218	232	030	118	416	126	120	00523	07067
220219	296	056	088	460	153	146	04143	10445
220220	368	030	080	498	104	101	00903	06217
220401	334	030	074	458	123	118	01103	08967
220402	232	078	072	382	128	128	04515	05295
220403	344	030	058	452	096	101	00866	04089
220404	474	062	072	608	128	128	05473	05019
220405	274	030	080	404	109	102	00862	07301
220406	336	030	078	464	108	104	00497	06688
220407	380	054	084	538	132	126	03535	07733
220408	238	030	072	340	095	095	00814	04003
220409	096	058	088	262	131	123	04431	07310
220410	252	060	082	828	135	108	04136	09404
220411	270	076	074	964	129	114	04637	06069
220412	258	050	092	420	122	117	02791	08846
220413	224	058	038	340	089	120	01062	02365
220414	458	086	068	612	125	125	06586	04340
220415	252	078	082	538	117	118	08713	03687
220416	250	068	096	560	128	102	04406	08746
220417	296	030	074	400	103	103	00651	06177
220418	216	076	108	428	126	113	04112	07740
220419	456	030	072	578	103	100	00326	06476
220420	332	072	060	464	122	122	06093	03533

240101	106	098	098	322	234	244	04076	06172
240102	284	124	176	660	241	241	05464	10704
240103	086	088	044	238	194	225	06642	02025
240104	280	086	154	578	264	242	06021	10349
240105	144	088	148	428	259	243	06838	09369
240106	550	078	180	844	244	234	03250	13777
240107	210	104	136	526	235	237	03759	05569
240108	366	098	104	570	226	224	04707	08213
240109	100	038	058	216	143	187	03704	00584
240110	264	082	138	632	243	240	05793	14577
240111	442	074	070	606	228	234	05996	06984
240112	182	060	146	432	249	238	04561	12731
240113	328	076	044	468	198	226	05737	02724
240114	096	094	208	418	229	232	02728	11775
240115	130	064	038	252	171	210	05093	03304
240116	156	102	046	324	165	194	03864	03390
240117	476	066	148	710	240	240	04888	13191
240118	468	064	092	644	251	248	05654	10995
240119	220	072	036	348	144	185	04361	01091
240120	246	080	046	392	152	196	05250	00522
240201	286	076	036	418	184	217	06865	01154
240202	096	072	044	232	176	214	03266	01801
240203	078	080	346	594	233	232	02121	17646
240204	070	064	204	412	251	251	05429	20349
240205	074	118	170	472	265	250	10061	11636
240206	070	094	036	220	181	211	06429	05752
240207	086	076	030	212	158	192	06408	02555
240208	128	030	032	210	136	177	00246	02092
240209	150	034	052	256	150	171	01574	02850
240210	108	030	592	750	196	184	00392	22426
240211	084	090	118	418	255	246	04934	09232
240212	114	054	030	218	162	191	02713	01293
240213	078	058	278	430	202	208	03572	17347
240214	072	076	052	220	164	196	01555	00874
240215	132	054	030	236	152	178	01383	00426
240216	086	036	084	226	203	208	00898	10093
240217	078	080	346	594	233	232	02121	17646
240218	090	084	224	452	251	240	05263	18632
240219	096	066	108	306	240	235	06258	12036
240220	128	088	128	458	256	242	05698	10022
240401	508	062	108	810	269	221	07711	19889
240402	350	084	110	564	303	281	07644	17693
240403	388	082	096	686	298	246	08501	16242
240404	316	086	098	520	287	272	06146	19624
240405	356	090	106	592	297	248	09436	16319
240406	428	088	098	630	292	272	07691	15165
240407	352	084	122	588	286	248	08140	20996
240408	454	082	102	768	300	225	08494	18524
240409	424	082	100	770	289	252	10680	12839
240410	394	080	114	632	289	245	06963	17040
240411	422	080	114	750	293	236	09802	17032
240412	334	072	172	600	237	229	07242	25937
240413	348	070	128	662	297	219	06225	19716
240414	306	080	112	646	289	233	09116	14494
240415	346	068	152	682	262	214	05323	16037
240416	404	056	148	640	257	229	03718	18115
240417	400	090	446	936	247	247	07592	85466
240418	462	092	180	756	238	226	07250	32376
240419	542	052	182	796	176	176	03557	32785
240420	522	052	124	718	278	260	04941	15466

310101	126	074	034	254	053	063	01497	01804
310102	100	030	030	180	052	069	00727	01399
310103	222	034	030	308	050	060	01272	02130
310104	136	056	070	390	064	057	02246	03571
310105	136	060	036	252	055	066	01972	01891
310106	108	078	030	238	054	069	03120	01715
310107	132	054	034	242	049	063	01437	01393
310108	098	066	054	270	083	052	04118	05422
310109	256	030	036	342	041	050	00830	01941
310110	226	048	030	324	053	069	01833	01439
310111	152	036	042	250	056	073	00793	02943
310112	134	054	042	250	060	073	01461	02623
310113	110	050	030	210	062	073	02280	01769
310114	146	094	054	314	056	060	01248	01926
310115	106	048	088	320	058	062	01542	02360
310116	156	052	094	360	066	062	02548	03215
310117	160	100	064	358	066	058	01852	01685
310118	140	030	036	258	068	062	01624	02342
310119	120	056	048	250	064	058	01248	01478
310120	258	058	124	458	066	060	02488	03214
310201	178	054	030	282	074	084	03109	01871
310202	142	048	056	266	078	079	02473	05602
310203	132	056	054	318	089	064	04576	04148
310204	280	038	110	448	080	066	01114	10143
310205	308	038	094	462	078	061	01263	12315
310206	110	102	078	334	073	061	02782	06446
310207	194	030	084	330	072	062	00590	08842
310208	134	042	084	312	082	054	02399	08733
310209	248	106	058	490	092	061	07400	04409
310210	122	042	090	278	084	073	02449	09755
310211	130	054	052	236	079	079	04326	03460
310212	352	104	078	576	095	077	06828	07624
310213	236	048	094	412	101	082	01559	10600
310214	222	092	064	426	090	067	03442	06636
310215	148	102	098	370	080	073	03572	07441
310216	100	112	066	338	085	052	05625	04377
310217	074	098	080	286	105	083	05886	08422
310218	142	030	080	292	077	053	01373	06359
310219	140	052	076	302	093	073	04438	06979
310220	166	030	062	278	075	069	00433	07347
310401	140	050	050	260	070	073	02369	03181
310402	074	052	030	176	057	073	01702	01920
310403	122	054	034	230	059	069	02308	01315
310404	158	046	110	334	067	060	01100	07363
310405	164	030	084	602	064	049	00835	05324
310406	152	052	030	254	061	075	02796	01116
310407	090	034	110	266	069	056	01249	07608
310408	214	050	030	314	068	062	02967	01367
310409	128	040	054	242	073	076	02067	03345
310410	136	036	096	302	068	058	01615	06350
310411	096	046	040	202	056	067	01589	01952
310412	088	052	132	292	066	056	01687	07157
310413	106	048	096	294	062	052	01654	04945
310414	112	038	046	216	060	066	01521	02024
310415	112	114	038	284	059	071	02893	00645
310416	090	106	060	276	058	066	03272	02687
310417	100	114	044	278	053	062	04990	01505
310418	110	046	092	332	073	051	01769	05194
310419	156	036	078	290	075	073	01261	06528
310420	240	030	040	330	066	075	00216	03930

320101	328	072	112	532	145	134	05123	16141
320102	152	060	118	350	138	124	03438	16210
320103	138	076	492	726	123	124	06395	27980
320104	172	106	070	370	150	144	05847	09381
320105	116	082	056	352	133	122	06686	04766
320106	198	074	082	374	143	134	03177	10945
320107	280	066	068	434	143	139	04654	10179
320108	238	070	058	402	136	125	07357	07797
320109	200	048	030	298	106	139	02871	02034
320110	142	046	118	840	129	123	03326	09525
320111	530	076	058	664	143	143	08555	08013
320112	130	070	386	920	120	124	04424	30119
320113	090	064	070	246	124	119	04860	07548
320114	080	080	086	298	145	123	05113	12528
320115	148	074	076	390	142	116	04927	10397
320116	094	056	032	202	096	125	02965	01373
320117	102	062	032	216	102	132	02771	02111
320118	292	030	164	506	130	125	01797	29252
320119	266	034	132	458	143	130	00389	24006
320120	136	054	104	328	124	102	03301	14863
320201	148	064	350	582	115	114	03026	58398
320202	180	088	436	734	113	114	08466	28471
320203	164	072	068	324	141	136	05718	09792
320204	240	078	090	428	148	141	06835	14096
320205	254	084	086	474	137	121	08253	11390
320206	404	080	050	996	147	119	09903	07636
320207	074	030	484	614	103	105	00919	58763
320208	138	092	050	300	125	123	05519	05495
320209	236	066	076	398	152	146	05176	11575
320210	274	080	048	494	147	123	06792	06044
320211	104	078	074	328	142	109	02971	09315
320212	304	078	104	512	145	126	04548	15720
320213	228	078	338	664	120	121	07309	43480
320214	120	062	058	322	140	107	04784	03348
320215	228	094	394	726	130	130	08000	33575
320216	084	050	032	186	097	136	03806	01253
320217	158	034	056	268	133	149	03164	09876
320218	130	090	064	354	157	132	06663	08573
320219	158	078	084	340	148	138	05797	11787
320220	070	030	108	244	122	111	01251	12603
320401	094	110	032	256	105	135	05093	02319
320402	124	092	040	276	102	133	03420	02749
320403	124	086	056	286	099	128	03346	00971
320404	116	096	036	268	081	109	04997	01346
320405	092	096	140	358	119	115	05177	09828
320406	188	100	104	412	140	134	04368	11252
320407	088	096	094	332	125	106	05866	07234
320408	162	108	072	342	109	109	06915	09477
320409	114	066	292	492	115	115	05210	23002
320410	096	060	070	646	136	123	03955	05851
320411	126	094	042	282	107	118	06086	02589
320412	134	100	090	344	137	128	07338	08329
320413	100	044	030	194	108	142	03644	01753
320414	076	038	100	234	127	124	01750	11422
320415	106	060	188	374	112	112	05208	29741
320416	088	058	082	268	130	125	03425	05599
320417	138	092	048	298	104	120	05994	01930
320418	078	096	038	232	085	109	03331	03661
320419	180	116	038	354	094	120	05340	01978
320420	070	036	154	306	120	112	02036	11380

340101	080	126	030	256	216	237	12192	00356
340102	072	118	034	244	198	221	11342	00470
340103	074	046	220	420	241	241	04265	27683
340104	082	160	040	302	219	242	10239	01261
340105	070	086	066	242	225	243	09599	03453
340106	154	030	158	368	194	185	00553	10710
340107	072	096	086	274	264	268	09738	05427
340108	088	076	236	446	244	245	09184	25368
340109	090	084	030	226	135	185	11088	01599
340110	088	110	182	638	273	247	13511	12568
340111	104	030	402	999	233	233	02498	58788
340112	092	078	140	482	254	251	07437	11891
340113	098	066	172	552	256	247	05767	14421
340114	070	050	030	170	201	241	05264	03769
340115	072	064	194	330	248	248	07623	21938
340116	078	072	112	284	262	262	07979	06995
340117	082	034	166	366	233	223	02588	07844
340118	072	048	304	424	242	242	05646	37112
340119	092	048	044	204	142	188	04913	06999
340120	098	100	162	538	263	241	12568	15632
340201	256	092	130	498	269	267	07568	12699
340202	358	064	130	688	256	247	05028	08950
340203	232	104	118	490	269	246	10264	14612
340204	198	092	030	340	194	233	10432	01658
340205	302	066	038	426	184	220	06736	02460
340206	290	042	052	404	155	204	03612	01307
340207	186	054	054	315	175	208	04022	02478
340208	212	096	116	424	269	269	09309	09645
340209	220	044	140	438	264	254	05976	13581
340210	466	088	144	828	267	258	06158	12168
340211	166	082	122	390	239	242	05473	11004
340212	256	102	030	408	202	244	08624	01820
340213	184	098	104	566	261	247	09354	11472
340214	326	092	106	996	263	248	08424	10067
340215	276	098	108	510	275	270	09533	10326
340216	234	076	116	446	268	263	07056	11003
340217	310	084	112	998	254	250	08335	11449
340218	262	096	110	492	254	251	06332	09702
340219	282	096	144	580	251	245	07408	13982
340220	154	084	034	292	185	232	09072	00600
340401	094	128	094	400	244	233	10906	09000
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340403	080	126	090	316	247	241	07917	13353
340404	092	032	170	314	220	214	01420	15821
340405	100	078	188	386	250	248	09893	22801
340406	142	118	054	334	211	237	06709	05980
340407	086	122	336	995	237	240	10296	47410
340408	114	118	104	502	248	233	11523	11000
340409	070	042	124	256	243	237	04438	14353
340410	230	112	108	470	259	255	10249	12811
340411	102	094	110	306	253	253	09532	09436
340412	118	076	032	246	183	229	06549	02086
340413	076	064	126	326	257	243	05181	12661
340414	092	074	218	424	243	234	03228	22487
340415	090	116	090	086	247	241	08919	12536
340416	100	089	156	368	250	244	08968	18635
340417	088	052	068	310	244	226	07584	12444
340418	098	122	144	458	256	238	08524	10111
340419	122	056	188	452	246	220	09886	12564
340420	254	056	125	608	232	232	08562	18562

410101	350	030	060	460	052	069	00398	01697
410102	278	050	030	390	059	071	02042	01692
410103	200	030	138	388	075	065	00265	09130
410104	248	050	034	352	055	068	01826	00684
410105	190	030	108	352	059	054	00317	05630
410106	194	030	052	286	062	069	00524	02969
410107	320	030	054	690	061	043	00546	01089
410108	240	078	050	388	077	080	03459	01928
410109	236	038	066	360	052	062	00347	00758
410110	194	030	064	308	057	072	00384	02353
410111	432	060	036	548	053	063	01769	00753
410112	222	058	042	342	046	059	00996	01466
410113	320	050	060	460	054	065	00569	01526
410114	256	060	050	396	058	066	02145	01368
410115	198	036	124	420	072	062	00865	02588
410116	248	050	034	352	055	068	01826	00984
410117	190	050	080	348	056	064	01254	00982
410118	254	060	036	368	059	061	00986	01266
410119	368	066	128	584	066	064	00854	02214
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410202	228	042	030	320	072	091	01837	00922
410203	206	058	034	318	076	097	01476	01787
410204	226	040	425	738	047	047	01153	19776
410205	186	062	044	312	090	093	03151	01730
410206	228	048	118	414	074	064	01333	10073
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410210	174	030	058	282	060	075	00212	02600
410211	206	064	042	332	085	092	03375	01827
410212	138	046	052	256	079	060	00986	03887
410213	118	054	092	284	094	086	02334	09748
410214	176	048	082	330	108	091	03666	06975
410215	152	032	048	552	077	048	00982	01763
410216	254	078	094	852	094	065	02489	04422
410217	240	050	030	340	071	062	01414	01650
410218	242	064	116	454	091	065	03438	05211
410219	406	038	030	474	055	055	01445	00592
410220	272	030	176	498	086	077	02144	14817
410401	324	046	096	490	092	073	01811	10176
410402	132	070	112	334	089	081	03703	06505
410403	238	050	092	400	101	094	03095	04192
410404	214	042	050	326	070	090	00873	01751
410405	280	030	070	422	080	058	00191	06609
410406	226	050	098	412	096	079	02451	09038
410407	206	042	036	304	060	081	01444	01093
410408	256	042	030	348	074	099	02068	00384
410409	070	034	418	542	045	047	01267	33069
410410	164	068	080	354	094	071	04294	04921
410411	270	056	078	440	101	087	03768	05925
410412	192	060	092	366	105	091	04128	07160
410413	148	050	030	248	069	091	02512	00902
410414	100	058	094	874	087	058	02341	08216
410415	152	062	122	356	095	085	03519	09209
410416	148	058	030	256	072	097	01804	00845
410417	136	054	072	330	110	079	04641	06589
410418	134	062	086	320	091	073	03559	05871
410419	100	070	030	220	078	066	02085	01192
410420	084	032	040	176	068	065	02599	03214

420101	282	038	158	498	123	115	02008	06722
420102	194	058	038	310	097	116	03760	00799
420103	086	072	042	220	118	137	03186	02646
420104	186	076	120	406	146	141	03137	05762
420105	330	050	040	440	097	124	02939	01260
420106	182	114	092	980	142	124	03942	04251
420107	080	054	064	218	126	125	02514	02567
420108	144	070	114	486	141	128	02832	06209
420109	140	060	080	280	161	141	06322	07002
420110	156	066	088	332	165	139	04814	07988
420111	246	040	130	490	130	112	02821	07219
420112	252	032	096	400	119	117	00851	05932
420113	260	044	044	368	087	107	01717	02038
420114	128	072	034	254	071	091	03103	00206
420115	074	044	052	190	102	125	01417	01687
420116	236	046	194	506	128	125	02311	09024
420117	146	102	030	298	115	139	02304	01644
420118	156	076	102	354	141	141	06182	07546
420119	278	050	046	394	112	135	02517	01905
420120	186	112	090	390	140	126	03842	04222
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420203	204	032	122	378	105	122	05422	03714
420204	142	140	032	334	127	139	08554	00666
420205	168	030	050	268	083	102	00868	01393
420206	172	100	030	322	101	118	04352	01588
420207	088	094	214	416	112	113	04421	09750
420208	133	114	438	722	116	119	02956	12974
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420210	174	116	110	918	258	247	06975	06805
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420210	148	146	144	580	275	246	10222	10250
420211	126	150	030	326	095	112	04037	00661
420211	246	096	084	446	263	272	08326	05752
420212	282	086	030	418	190	236	05687	01171
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420213	078	050	040	192	090	120	02322	01021
420214	224	030	030	304	150	191	02474	01945
420214	182	058	058	408	117	128	07128	04214
420215	186	066	102	458	128	122	05684	05662
420215	176	094	032	322	175	219	05475	02775
420216	200	098	188	506	277	271	07880	16841
420216	158	030	036	310	126	122	06548	07524
420217	248	066	043	382	172	216	04232	02426
420217	258	088	066	432	136	125	07854	08566
420218	242	102	110	636	265	243	07971	06469
420218	158	056	036	288	122	120	05422	04526
420219	166	058	098	332	145	128	06524	07852
420219	236	052	076	384	193	231	02710	02324
420220	328	106	116	708	282	252	04109	09504
420220	202	078	120	420	136	128	04562	03210
420401	178	082	076	502	148	130	04520	04199
420402	160	088	096	364	147	143	06788	07038
420403	162	056	118	356	139	136	03184	06748
420404	132	104	092	636	143	130	06016	02025
420405	162	136	088	386	129	129	06686	03459
420406	102	058	038	218	094	116	03493	00884
420407	224	034	084	342	121	121	00814	04336
420408	218	070	030	338	089	114	02471	00955
420409	078	050	114	262	135	133	03359	07329

420410	174	030	090	464	098	098	02458	05221
420411	116	056	108	280	136	136	02051	06961
420412	206	034	034	294	081	102	00500	02568
420413	144	036	246	446	110	109	00859	15382
420414	228	030	132	420	103	096	01533	06920
420415	244	030	132	326	137	136	05217	03018
420416	318	030	142	530	106	123	05217	07661
420417	140	036	190	386	117	114	05807	09427
420418	206	068	110	404	126	122	05624	08542
420419	198	088	102	408	145	125	08974	10256
420420	254	060	036	340	128	122	06548	07632
440101	284	080	034	418	189	229	07980	01781
440102	252	072	048	392	171	204	05314	02531
440103	222	058	194	494	248	247	03626	08414
440104	296	072	036	424	174	209	04173	02287
440105	176	098	030	324	189	228	06757	01990
440106	238	066	038	362	175	215	05410	02093
440107	132	068	234	454	252	248	04331	22947
440108	222	096	100	438	264	268	07072	08094
440109	250	066	136	804	289	256	06355	07614
440110	202	092	038	352	190	227	08515	02562
440111	182	078	056	336	169	198	04385	02722
440112	106	082	034	242	187	218	06317	01890
440113	228	030	088	368	197	208	05429	06432
440114	226	074	042	362	224	273	05705	02397
440115	278	030	112	468	185	182	01228	07773
440116	102	172	132	326	248	244	05735	10044
440117	170	086	054	288	171	207	04971	02411
440118	226	102	040	388	199	243	06305	02141
440119	128	076	030	254	182	228	05960	01000
440120	154	080	036	290	185	225	05573	02595
440201	212	090	030	352	195	252	06617	00972
440202	226	132	036	414	211	248	11322	01099
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440204	242	074	176	512	240	232	04751	16336
440205	296	086	034	436	188	226	04633	03139
440206	388	084	072	564	229	240	06532	04004
440207	230	080	038	368	201	237	08058	02841
440208	290	108	036	454	178	214	04093	01636
440209	364	084	030	498	205	243	03959	02930
440401	494	056	126	776	229	230	05349	07920
440402	564	052	156	970	246	230	03063	08312
440403	238	096	030	386	195	222	08774	02793
440404	406	030	158	614	215	215	05561	10285
440405	560	044	278	902	224	225	02068	12715
440406	370	076	030	496	168	198	05096	00476
440407	282	030	098	430	180	207	05710	04472
440408	252	104	148	996	242	245	05564	07075
440409	236	126	034	416	183	219	04529	01002
440410	160	106	402	694	245	246	06019	17440
440411	172	140	090	402	252	252	06527	03223
440412	164	094	124	448	246	241	08469	08104
440413	188	124	130	462	231	234	04421	06924
440414	206	152	326	704	242	242	05820	14328
440415	320	166	112	662	236	228	06605	07108
440416	258	160	116	996	264	251	12030	05646
440417	198	124	044	386	179	211	05167	01022
440418	172	106	336	924	245	249	05534	12873
440419	282	030	036	368	226	238	07548	09542
440420	310	040	040	410	228	241	08571	07024

510101	366	054	090	600	092	053	04960	09909
510102	342	052	102	518	087	059	04728	20201
510103	252	066	090	508	104	067	06228	12738
510104	252	062	082	502	094	044	05112	09847
510105	322	034	072	532	105	043	03037	11018
510106	254	070	100	444	080	058	06283	16515
510107	266	068	072	426	087	069	03926	11870
510108	333	062	096	514	076	060	04311	19510
510109	272	076	072	520	085	049	04233	08081
510110	312	060	096	478	072	057	04929	18971
510111	262	074	064	420	107	081	06069	11582
510112	344	058	062	488	086	058	05304	10369
510113	288	064	036	706	107	062	05773	04517
510114	324	058	068	470	090	073	04558	14656
510115	300	052	088	460	068	056	05377	17288
510116	278	066	070	502	086	047	05326	08020
510117	350	050	072	492	104	078	04083	12835
510118	420	058	068	570	085	056	04477	12037
510119	388	068	082	622	103	053	05864	11528
510120	208	054	062	410	085	053	04959	08100
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510202	366	072	112	638	079	054	00936	07488
510203	396	060	094	582	067	052	03190	14192
510204	434	072	064	688	101	061	07910	07109
510205	488	062	072	714	097	053	06688	07372
510206	528	066	072	752	078	047	07240	04588
510207	454	050	072	596	096	070	03586	11722
510208	406	054	074	616	083	043	04549	10739
510209	454	072	100	646	055	042	04744	22334
510210	448	066	068	666	088	039	05991	12770
510211	430	074	070	654	075	033	06546	09670
510212	458	056	094	660	057	035	03318	13971
510213	456	054	104	636	053	038	03935	24491
510214	500	054	072	646	080	058	03879	10434
510215	462	072	096	650	053	038	05893	25663
510216	410	058	076	624	079	041	03191	11054
510217	400	072	104	596	059	045	05394	24853
510218	476	070	102	668	055	034	05276	24345
510219	426	056	082	584	066	046	03033	11919
510220	406	052	068	556	076	049	03124	08197
510401	346	068	066	574	100	049	07036	07651
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510403	372	066	070	608	096	053	05639	06523
510404	422	064	074	646	087	043	04600	10541
510405	440	058	034	552	084	065	04098	01034
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510407	492	064	076	652	090	068	02049	10669
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510410	394	066	070	624	102	058	06528	07209
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510413	422	052	086	584	086	058	01250	13054
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510416	484	062	082	722	088	050	04688	10162
510417	394	054	074	564	100	055	04183	09487
510418	384	068	070	608	098	051	07383	05248
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510420	402	056	094	574	079	054	03483	13360

520101	070	038	162	292	124	121	02779	10571
520102	110	052	110	358	118	112	02783	05032
520103	100	060	098	258	156	156	04580	06294
520104	090	064	142	344	137	130	02734	08655
520105	384	068	030	502	110	130	04503	01270
520106	078	080	096	274	147	139	05689	06035
520107	114	066	088	314	141	135	05027	05428
520108	084	074	042	220	125	131	05014	02591
520109	110	066	118	748	129	122	03139	05840
520110	098	062	030	210	095	123	04179	00469
520111	106	042	066	334	133	131	02342	12261
520112	142	094	070	436	136	122	07230	03367
520113	478	078	134	756	150	123	04788	07641
520114	118	072	036	240	081	104	02691	00661
520115	134	064	088	352	148	126	04713	07996
520116	116	080	042	258	138	144	05470	06095
520117	120	064	092	468	141	122	04312	05103
520118	206	046	132	426	129	114	02587	10421
520119	186	066	130	438	139	127	04136	11172
520120	202	050	030	302	101	129	03939	00800
520201	346	076	094	626	150	108	04565	11600
520202	512	078	076	692	151	125	06700	11210
520203	310	060	046	436	154	127	06462	01568
520204	342	076	082	600	057	126	06466	13164
520205	360	080	088	554	150	126	04436	12780
520206	380	058	106	568	147	123	04368	15802
520207	306	074	116	516	130	114	04661	18222
520208	340	056	116	532	140	122	04376	14535
520209	244	084	112	460	145	119	09159	29883
520210	292	072	104	506	155	117	05294	11579
520211	314	100	092	554	150	103	06697	09192
520212	428	088	134	660	118	109	07281	25376
520213	400	082	322	824	121	122	06308	55552
520214	324	082	108	608	145	100	07311	13784
520215	416	072	088	618	163	115	07208	13877
520216	384	084	092	596	144	111	05728	13404
520217	306	096	084	618	148	107	06154	12585
520218	322	084	084	998	173	115	09012	13196
520219	474	070	084	674	185	128	06754	13871
520220	410	076	112	618	134	112	08388	23674
520401	514	078	088	724	172	122	06845	15052
520402	360	048	112	550	145	109	03058	13725
520403	364	082	082	654	141	107	06743	11211
520404	390	062	108	590	147	114	04958	13733
520405	414	082	092	690	138	102	04819	10680
520406	388	056	086	698	148	115	05954	14302
520407	364	060	084	530	150	127	05869	13566
520408	358	066	072	516	157	141	04490	07754
520409	422	084	060	732	163	114	07986	10127
520410	388	060	036	504	121	146	03996	01447
520411	342	058	110	532	135	117	02581	15373
520412	342	080	088	542	176	131	07493	14630
520413	398	056	104	592	155	111	06315	16761
520414	382	058	118	580	153	130	04205	16871
520415	398	084	100	602	139	118	09356	19066
520416	446	076	086	654	157	105	05572	15484
520417	296	076	032	424	154	120	05589	04512
520418	240	082	036	378	184	228	07710	01384
520419	318	070	106	522	139	110	04723	13221
520420	346	078	090	550	161	119	07624	13129

540101	570	066	130	870	287	221	08244	20164
540102	448	144	114	882	310	240	07862	14116
540103	418	100	146	746	274	227	04978	17327
540104	426	120	128	694	308	268	08337	17244
540105	518	144	040	622	205	262	02655	02624
540106	488	034	144	690	241	217	02464	18412
540107	452	130	126	756	289	245	07543	14457
540108	552	084	110	886	285	220	08087	13374
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540111	432	062	056	570	246	280	07120	01021
540112	338	114	098	570	304	270	10906	12735
540113	398	072	112	660	290	215	05631	12567
540114	440	038	136	734	234	197	01124	16502
540115	532	084	086	850	291	222	09296	14145
540116	396	054	144	692	235	197	02261	17231
540117	446	052	114	668	240	208	02703	14038
540118	490	030	060	600	200	242	01645	00368
540119	430	098	142	692	266	244	05597	17414
540120	486	072	110	688	280	261	05868	14365
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540202	648	072	108	936	276	230	08986	15313
540203	588	068	128	928	277	237	08987	14264
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540207	712	066	034	832	216	267	07463	02949
540208	480	086	096	682	279	252	09267	17250
540209	530	068	132	750	260	231	06514	21189
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540211	528	090	122	760	266	240	07462	21921
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540213	582	098	128	856	264	231	12035	16595
540214	458	092	116	798	271	237	05800	16046
540215	502	106	030	658	205	256	05263	01634
540216	532	098	120	846	281	236	09981	15787
540217	572	040	128	900	230	192	04226	19033
540218	430	114	132	768	255	228	05324	17208
540219	524	090	134	830	282	237	09481	15400
540220	604	068	110	802	279	262	09242	14707
540401	444	104	098	840	303	266	11385	13741
540402	452	076	050	598	223	264	04200	04286
540403	426	092	114	692	304	248	05014	20891
540404	454	084	114	766	292	226	08919	16548
540405	248	096	122	586	292	227	08704	19476
540406	324	114	038	496	239	279	09732	01785
540407	352	080	140	608	272	235	06175	24000
540408	444	032	044	540	199	232	01639	02455
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540410	198	232	114	736	285	241	12450	14745
540411	304	072	146	570	274	237	05936	20888
540412	088	222	046	376	252	285	11398	01583
540413	378	078	136	772	269	238	05680	16258
540414	322	092	120	566	271	238	09119	19271
540415	350	076	044	490	236	284	05785	04597
540416	362	072	138	646	295	247	10454	12186
540417	300	076	108	676	274	240	09022	15211
540418	342	100	118	734	293	226	10640	17513
540419	388	046	030	484	209	246	03839	02522
540420	510	042	086	658	243	229	03042	11178